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THE GERMAN STEEL CASTINGS INDUSTRY

BY

CHARLES W. BRIGGS AND MAZ T. GANZAUGE

FOREWORD

The following report was prepared by the authors as the result of a trip to Germany in the summer of 1945 for the Technical Industrial Intelligence Committee, Subcommittee on Metals and Minerals. The purpose of this Committee, which functioned under the Joint Intelligence Committee of the Joint Chiefs of Staff of the United States armed forces, was to obtain information of interest to American Industry and of value to the United States Joint Control Council for Germany.

This paper was submitted through the Joint Intelligence Objectives Agency, which absorbed T.I.I.C., and was released for publication through the Bureau of Mines. In all cases the individuals or teams sent on the investigating missions were chosen from the best-qualified men available in the industry and in the various Government agencies.

The authors are not employees of the Bureau of Mines, but their report is published by the Bureau in order to give it circulation in appropriate circles.

I. C. 7362,
August 1946.

INFORMATION CIRCULAR

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

THE GERMAN STEEL CASTINGS INDUSTRY[1]

By Charles W. Briggs[2] and Maz T. Ganzauge[3]

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is made: "Reprinted from Bureau of Mines Information Circular 7362."

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INTRODUCTION

Purpose of the Investigation

The steel foundries of Germany were investigated for the purpose of ascertaining (1) the type and classification of steel structures produced as castings, (2) processing methods, (3) the mechanical properties of carbon and alloy cast steels, (4) the type and character of defective castings, (5) the appearance of castings, (6) research in steel castings, and (7) plant lay-out and equipment.

The processing methods invesgigated consisted of the following: (1) Raw materials, (2) steel-making practices, (3) tapping and pouring methods, (4) preparation, distribution, and reclamation of molding materials, (5) sand technology, (6) molding and core-making practices, (7) cleaning technique, (8) welding of steel castings, (9) heat-treatment methods, and (10) inspection and testing practices.

Scope

To accomplish the purposes of the investigation, the investigators made a complete and exhaustive survey of the steel foundries in Germany both before entering and after arriving in Germany to ascertain (1) the names of steel-casting companies, (2) their location, (3) the size of the organization in terms of production, (4) the character of the organization as to quality of product, and (5) the progressiveness of the individual company. This was done so that a relative cross section of the German steel-casting industry could be visited and studied. It was the desire of the investigators to visit large, medium, and small steel foundries as well as foundries that were considered the leaders of the industry, and concurrently to visit representative foundries that enjoyed no outstanding reputation.

Further, it was the wish of the investigators to visit foundires that produced (1) only steel castings, (2) ferrous castings other than those of steel, and (3) steel plants that produced wrought-steel products as well as steel castings.

According to 1944 German steel-casting industry records, there were approximately 200 steel foundries in greater Germany. It is evident that all 200 foundries could not be investigated in the time the investigators has available, but it is their opinion that the targets covered represent an excellent cross section of the German steel-casting industry in all the categories listed above. Tonnages produced by the companies investigated represented 28.2 percent of the production of steel castings for greater Germany for 1944.

Steel foundries at the following companies were investigated:

1. Ruhrstahl, Annener Gussstahlwerke, Annen.
2. Ruhrstahl, Henrichshütte, Hattingen.
3. Ruhrstahl, Gelsenkirchener Gussstahlwerke, Gelsenkirchen.
4. Ruhrstahl, Stahlwerk Krieger, Oberkassel.
5. Bochumer Verein, Bochum.
6. Bochumer Verein, Weitmar.
7. Friedrich Krupp, Essen.
8. Deutsche Edelstahlwereke, Bochum.
9. Bergische Stahlindustrie, Remscheid.
10. Deutsche Eisenwerke, Mülheim.
11. Gussstahlwerk Risch, Bergisch-Gladbach.
12. Röchlingsche Eisen und Stahlwerke, Völklingen.
13. Saarländische Stahlwerke Dingler, Karcher Co., Saarbrücken.
14. Heckel-Werke, Rohrbach.

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15. Buderus Eisenwerke, Wetzlar.
16. Eisengiesserei Streicher, Ludwigsburg.
17. Reichswerke Herman Göring, Linz Alpine Montane Betriebe.
18. Eisengiesserei Rodinghausen, Menden.

The period of the investigation was July 15 to August 28, 1945.

SUMMARY

Production

The German steel-casting industry was an important factor in helping the German Government to prosecute the war. Production was increased threefold over normal peacetime production. Castings weighing a few ounces to those weighing 230 tons were manufactured during this period. Most of them were armament castings or parts of equipment to be used by the armed forces. Major classifications were armor castings; tank, tractor, and automotive castings; aircraft, submarine, and ship castings; projectiles, guns, and gun carriages and parts. Castings intended to assist the prosecution of the war were synthetic- gasoline cracking-plant castings, locomotive and railroad castings, mining equipment, castings for heavy machinery such as presses, and power plant-equipment castings.

Some of the castings produced normally would not be made as steel castings, as they were more economically suitable as drop forgings, forgings, or weldments. Such items were produced because of the limitation of forging equipment.

In tables 1 and 2 is presented a statement taken from the records of the Vereindeutscher Stahlformgiessereien (the trade association of the German steel-casting industry) of the production of liquid steel for castings for 1943 and 1944 broken down into tonnages produced by the various melting units. These figures are very nearly all-inclusive of the entire steel output for castings, as the association was a semi-official government body, and represent the tonnages of 198 steel foundries. A study of the tables indicates that maximum production of liquid steel for castings was not reached until April 1944, when the quantity of steel produced equaled 166 percent of the normal rated capacity of 100 percent fixed as of September 1938.

Peak production for the various melting practices and the increase over the rated capacity as of September 1938 follow:

Steel-making method	Month	Percent of Sept. 1938
Open-hearth	Sept. 1938	100
Electric	June 1944	245
Converter	April 1944	297

TABLE 1

Month	Production of liquid steel in 1943, tons1/				Percentage increase over September 1938				
	Open hearth	Electric	Converter	Total	Working days	Open hearth	Electric	Converter	Total
January.....	56,506	41,168	48,355	146,029	25	79.8	171.3	215	135.7
February....	52,161	42,045	49,436	143,642	24	72.9	188.6	238.5	141.5
March.......	59,362	47,477	56,720	163,559	27	74.9	189.6	242.2	144.5
April.......	49,996	42,876	49,223	142,095	24	65.7	194.4	234	138.9
May.........	52,889	39,412	42,115	134,416	26	61.8	149.7	163.6	108.1
June	45,802	38,981	39,867	124,650	25	45.7	156.8	159.8	101.2
July........	48.152	41,730	41,407	131,289	27	41.9	154.5	149.8	96.2
August	42,504	36,717	39,561	118,782	26	30	132.6	147.9	84.4
September...	43,856	44,065	51,402	139,323	26	35	179.2	221.9	116.2
October	47,444	44,484	57,222	149,150	26	45.2	181.9	258.5	131.5
November ...	49,365	46,769	59,714	155,848	26	51.1	196.4	273.9	141.9
December ...	45,245	47,867	59,740	152,852	26	38.4	203.3	274.2	137.2
				1,701,635					

1/ Source: Verein deutscher Stahlformgiessereien.

TABLE 2

Month	Production of liquid steel in 1944, tons1/				Percentage increase over September 1938				
	Open hearth	Electric	Converter	Total	Working days	Open hearth	Electric	Converter	Total
January.....	48,633	49,224	59,546	157,403	26	48.8	211.9	272.9	157.9
February....	51,462	48,367	59,889	159,718	25	63.8	218.8	290.2	157.8
March.......	53,663	53,719	63,577	170,959	27	58.1	227.6	283.5	155.5
April.......	48,085	47,678	56,087	151,850	23	66.3	241.5	297.1	166.4
May	50,413	51,953	58,532	160,898	25	60.4	242.3	281.3	159.7
June........	50,931	54,417	61,202	166,550	26	55.8	244.8	283.4	158.5
July........	51,275	52,426	60,188	163,889	26	56.9	232.1	277	154.3
August......	49,457	51,425	62,878	163,760	27	45.7	213.6	279.3	144.7
September...	49,412	47,233	61,038	157,683	26	51.1	199.3	282.2	132.7
October.....	45,554	45,026	53,177	143,757	26	39.4	185.3	233.2	127.1
November ...	38,017	35,789	40,002	113,808	26	16.3	126.7	150.6	76.7
December ...	30,280	31,900	35,047	97,227	24	10	118.9	137.8	63.5
				1,807,502					

1/ Source: Verein deutscher Stahlformgiessereien.

The effect of bombing upon the industry can be seen in tables 1 and 2. Open-hearth production dropped off to 30 percent in August 1943, but increased to 66 percent in April 1944. However, the bombing in October through December 1944 reduced production to 10 percent of that of September 1938. Electric- and converter-steel production likewise was affected to such a degree that by December 1944 production was only half what it had been in October 1944.

The reduction in liquid-steel production for castings to the low figure of 63 percent of normal capacity production was not altogether due to the direct bombing of the plants. Many plants were forced to retard or stop production resulting from the bombing of rail and water communications, thus preventing shipment of supplies and finished castings.

The records indicated that in normal peace time about 120 steel foundries were engaged in the manufacture of steel castings, either as captive foundries or as organizations producing castings for sale on the open market. Most of the additional 78 foundries engaged in the manufacture of steel castings were gray-iron foundries that made steel castings for the war effort at the request of the German government. Virtually all of these foundries produced the required steel by means of the converter practice. Thus, in April 1944, the peak of casting production, converter steel constituted 37 percent of total production, whereas electric-furnace steel was 31 percent and open-hearth was 32 percent of the total production of liquid steel. Many foundries producing electric furnace steel or open-hearth steel, or both, also made converter steel for castings.

Types and Classifications

Armor castings and structural part castings for tanks constituted the greater part of the steel-casting production during the war. Other important types were aircraft castings, ship castings, automotive castings, and shells. Production running into several hundred thousand shells per month was produced as steel castings in permanent molds. It is interesting to note this development, especially in view of the fact that our own military authorities did not look upon the production of cast-steel shells with much favor. An equally interesting development was the large-scale production of aircraft steel castings, far exceeding the United States aircraft requirements as to classifications and tonnage. Another prominent development was the manufacture of castings for the West Wall fortifications. Many of these, more properly known as cupolas, weighed upward of 220 tons.

Steel castings were produced centrifugally as well as statically, the predominant centrifugal classifications being cylinder liners and gun castings.

Raw Materials

Selected steel scrap was not always available for the production of steel castings, and in many cases light scrap, bundles, and tin cans were used. Pig iron high in phosphorus and sulfur often was used for converter steels going into shells and structural castings. Many foundries were required to use the Sonderborg type of electrodes produced by the steel-making companies. These electrodes broke easily and burned unevenly to long, tapered points. Alloys such as nickel and molybdenum were restricted and used very sparingly. Chromium was the most favored alloy element, manganese ranking second. Vanadium, especially in conjunction with chromium, was prominently used. Most all foundries had an adequate supply of ferro-silicon, ferro-manganese, and spiegeleisen. Most furnace refractories were adequate for the production required.

The German steel-casting industry has normally produced a considerable tonnage of steel castings in chamotte, supplies of which were adequate. The small and thin-sectioned castings were normally molded in a Belgian natural bonded sand. This sand became unavailable for foundry use rather early in the war, owing entirely to lack of adequate transportation facilities. Foundries then proceeded to use local natural bonded sands, and in several cases a silica sand bonded with cement was used. The quality of sand shipments varied considerably because of lack of proper mining operations. This condition required the constant variation of sand mixes. The primary difficulty was to procure bonding materials, such as a substitute for bentonite, and proper organic binders, such as cereals and oils. As the war continued, the cereal binders deteriorated in quality. For the most part, a dextrine produced from potatoes was used, but towards the end of the war the potato requirements were such that potatoes could not be allotted for dextrine production. Only very important cores were produced with core oil as a constituent.

Foundry production equipment such as molding machines, cleaning-room equipment, furnaces, etc., was available, but only in limited quantities.

Steel Melting

Melting practices were fairly uniform throughout Germany. The basic practice was used almost universally for steel produced in open-hearth and electric furnaces. Acid steel was not considered to be quality steel. It was the desire to keep the sulfur content to 0.02 percent, especially as a remedy for hot-tear formation. It was the normal practice to take off two, three, or more slags, both oxidizing and refining, in order to reduce the phosphorus and sulfur contents. It was the belief that dolomite-lined furnaces assisted in the removal of sulfur. It was normal practice to keep electric heats from 1 to 2 hours under a white disintegrating slag.

Most open-hearth furnaces were small, of 30 to 35 tons capacity, as it was the opinion of the German steel maker that higher-quality could be made in such furnaces. Companies producing castings of 100 to 200 tons preferred using a number of small furnaces, tapped simultaneously, to using one or two large furnaces. Only one 200-ton open-hearth furnace was seen, and this was primarily for the production of ingots.

Most of the furnaces - open-hearth, electric, and converter - were lined with rammed monolithic linings.

The practice followed for acid-lined open-hearth and electric furnaces was primarily that of a straight melt-down partial oxidizing practice with basic steel scrap used as the furnace charge.

The converter practice consisted normally in the production of steel with sulfur and phosphorous contents of about 0.10 percent each. In many cases desulfurization of the cupola metals is not practiced, and when it is followed, sulfur reduction is not pronounced. Quite a number of foundries used both converter and basic electric furnaces; the triplex practice was not used. Many of the technical directors thought that such a practice might have merit, but they had not found the opportunity to develop it for commercial production.

Slag control and slag analyses studies were not carried out, and considerable reliance was placed on the experience and judgment of the steel melters, many of whom had worked for a particular company for many years. It was noticed, however, that many heats were outside the range of analysis. Equipment for rapid analysis was for the most part not available. Steels to grain-size specifications were not required, and very few studies of fluidity had been made. Only one steel foundry maintained fluidity requirements as established by routine testing.

Deoxidation practices were varied. Aluminum additions often were made to the furnace prior to tapping, and little attention was given to quantities of aluminum used or the type of inclusions obtained. Low ductility results normally were blamed on included slag and not on inclusion types.

It was the normal practice to preheat the ferroalloys, especially ferrosilicon. Preheating temperatures ranged from 1,200° to 1,600° F. The purpose of preheating was primarily to drive off the hydrogen content. Considerable care was taken by most foundries' steel melters to prevent moisture from coming in contact with the bath. All slag-making materials, tapping spout, and ladles were carefully dried, and water connections were watched closely for leaks. This was done to keep the hydrogen content of the bath low. No studies were made on the gas content of production steels, so an estimate of the importance of preheating alloys and slag materials was not available.

Molding Practices

All large castings were molded in chamotte, except a few made in cement-bonded sands. Chamotte is a very open molding material, and an impermeable face is obtained by applying a rather thick coating of a mixture of graphite and finely ground chamotte. The surface appearance of castings so produced is good, provided the facing sand is new chamotte. Most foundries do not use the chamotte as received, but mix it with various proportions of used chamotte or a mixture of chamotte and sand. These mixtures, known as "Form Masse," become quite dense, depending on the amount of sand added, and do not produce castings of a very good surface appearance. The chamotte molds are oven-dried at temperatures approaching 1,000° F.

Most of the sands used for steel molding are composed of mixtures of quartz sand and natural bonded sands. These sands are quite fine, having an average grain size between AFA 75 and 100. The sands are very gummy, and it is not unusual for the clay content to be 12 to 15 percent. The moisture content was not carefully controlled, and for those sands that were to be dried no attempt was made to fix the percentage of water to be added.

The green-sand practice, as it is known in Germany, is an air-drying practice, in that molds are permitted to air-dry at least 12 hours prior to pouring. Air-drying produces a very hard mold, owing to the large percentage of clay present.

Most molds were prepared on jolt machines. A number of foundries had large jolt roll-over machines that could handle 5- to 10-ton molds. The practice of assembling large molds out of cores was not used. Molds were produced in pit forms with chamotte as the molding material.

Considerable care is given to the use of collapsible materials in the backing sand, such as hay, rope, ashes, cinders, etc. Metal relieving blocks also are used on large castings.

There is no sand-reclaiming equipment in Germany. Used sands are merely remulled with water. This results in the use of approximately 1 ton of sand for every ton of castings poured.

Most sand-handling equipment is inadequate, and piles of sand can be seen throughout the foundry. In many cases sands are distributed to hoppers that feet molding machines by cranes. Conveyors for removing molds from molding machines are few. The normal practice is to carry molds to the pouring floor or to have large overhead cranes pick up molds too heavy for two men to carry. It would seem that the general rule in steel foundries in Germany has been to use manpower whenever possible instead of machines. Mechanization has not been the rule on the molding floors in the German steel foundry.

Most core rooms are not modern except for the one outstanding feature of core blowing. Virtually all steel foundries, regardless of how small, have at least one core-blowing machine. Many foundries have 4 to 8 core-blowing machines. Cores weighing more than 60 pounds are blown on these machines. It is indeed a contrast to observe the lack of mechanization in the molding and core departments and at the same time to find core-blowing machines in operation. This is indeed a development, for despite the mechanization of American steel foundries there are but few core-blowing machines in operation. Core blowing was used extensively for cores for shells and track-shoe castings. A number of foundries employed the Georg Fisher Co. sand-testing apparatus. Apparently, however, the properties of sands at high temperatures were not being tested.

The lining of core boxes with hard rubber for the blowing of cores was an interesting development that increased the life of the core box. The rubber lining could be removed and a new lining of correct dimensions inserted.

Tapping and Pouring Methods

The steel is tapped over extremely long spouts at both electric and open-hearth furnaces. These spouts are brick-lined with chamotte rammed over the brick. The spouts are not too well maintained. Most ladles are lined with chamotte brick, and most are bottom-poured. Very little hand-shanking of basic steel is carried on. Converter steel is hand-shanked extensively, but all shells produced from converter steel are bottom-poured. In two foundries a basin is attached to the ladle so that individual pouring cups on molds are not necessary. No studies have been carried on regarding the rate at which the metal rises in the mold.

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Gating, Risering Technique

Whenever possible it is the practice to use top or parting gates. The French type of open-side is very popular and is considered more efficient in producing directional solidification than the step gate. Gating practice is similar to that normally employed in the United States.

Risers are used extensively and are large. The normal yield is 50 percent, and on certain aircraft castings the yield may be as low as 30 percent. The length of nearly all risers was at least twice their diameter. In only one foundry were riser lengths equal to 1.5 times the riser diameter or width. Many foundries used long, tapered necks on the risers. Technical men from progressive foundries claimed that this practice was not conducive to good technique. Many foundries attempted to follow the practices laid down by Heuvers of the Bochumer Verein and were familiar with his requirements concerning the feeding of castings through the employment of the technique of inscribed circles. Only two foundries investigated employed the practice of padding castings, though others attempted to have castings designed so that the inscribed-circle technique would be effective. Most foundries had one man or a group of men responsible for gating and risering practices.

Little attention was given to center-line weakness, as not many castings were radiographed. Secondary shrinkage under risers was often observed.

On all castings containing risers over 12 inches in diameter it was the practice to use portable electrode units and arc on the open riser to keep the metal hot so that the riser would feed the casting efficiently. The portable electrode units contained one, two, or three electrodes, depending on the diameter of the risers being used. This practice was an excellent one and should be adopted more universally.

Cleaning Practices

For the most part, extensive and modern cleaning equipment was used. This was necessary in view of the large proportion of castings containing "burnt-on" sand. In most cases heat treatment preceded the cleaning operation, so that the scale formed by heating the castings assisted in removal of the sand.

All foundries contained large, circular, cold saws for the purpose of removing risers 4 inches and larger in diameter. This procedure was followed because of the cost of oxygen and acetylene. Removal of risers by sawing would take five to six times as long as to remove them by torch cutting.

No studies were made as to grinding costs, pressure applied, or wheel wear.

Heat Treatment

Most castings were given an annealing heat treatment. Normalizing, as practiced in the United States, was not commonly used. For the most part alloy steels were quenched and tempered. Hardenability studies were not made to assist in quenching and tempering practices, and time quenching was not practiced. Water or oil quenching was employed, depending on the alloy composition, the carbon content, and the thickness of sections. The government specified oil quenching for all casting compositions containing nickel and water quenching for those without nickel. Only a few continuous furnaces were seen. The mechanical equipment for quenching did not usually lend itself to fast quenches or time quenching.

Welding

Welding requirements for aircraft and tank castings were strict as to the amount of welding permitted. Welding procedures or qualification tests were not specified. Welded areas must have the same strength as the casting after a full heat treatment. Atomic hydrogen welding was used considerably, especially on light sectioned castings. Heating to above the critical range was necessary on aircraft and armor castings.

Inspection and Testing

Most castings, either small or large, had poor surfaces. In many of them metal penetration and pinhole porosity were very prominent. Sand, slag inclusions, and buckles also were fairly extensive. Hot tears and shrinkage cavities were found occasionally.

Very little use was made of radiography. The X-ray machines were small, and radium was not used. Mesothorium was used in a few instances, but no foundry owned mesothorium and it was supplied by the government inspection services. Magnetic particle testing was used on all aircraft castings as well as a hot-oil seep test.

The tensile properties of castings were good, but only occasionally were reduction of area values required. A considerable amount of impact testing was carried on, and in some cases notched bar impact values were specified. Tensile test bars were always attached to the castings, and the thickness of the bars depended on the average casting section. No reductions in properties were permitted for the heavier sections.

It is the opinion of the investigators that the quality of the steel castings as a whole produced in Germany was not equal to the produced in the United States.

Centrifugal Castings

The horizontal centrifugal casting of tubes and gun barrels in a water-cooled mold with a thin sand coating was a new and novel practice and is not employed in the United States. The use of air pressure for operating centrifugal machines for liners also was new. The casting of guns in a vertical centrifugal casting machine also was not practiced in the United States.

The centrifugal casting of molds on a turntable machine operated by a vertical spindle was used, but not extensively.

Permanent Molds

The casting of shells in permanent molds with sand cores was very extensive and was accomplished with considerable success. Most of these shells were made of converter steel.

PART I. - RUHRSTAHL A. G.

The Ruhrstahl Company operates four steel foundires, as follows:

1. Ruhrstahl Annener Gusstahlwerk, Annen.
2. Ruhrstahl Henrichshütte, Hattingen.
3. Ruhrstahl Gelsenkirchener Gusstahlwerke, Gelsenkirchen.
4. Ruhrstahl Stahlwerk Krieger, Oberkassel.

The Ruhrstahl Company also operates a plant at Witten, known as the Ruhrstahl Gusstahlwerk, Witten. This plant, however, has no facilities for the production of steel castings and makes wrought steel entirely. The central offices of the company are at Witten. The Ruhrstahl executives estimated that their company manufactured approximately 50 percent of all the low alloy-steel castings and 20 percent of all the carbon-steel castings produced in Germany. A statement was also made to the effect that all the steel-casting engineers of the company met once or twice a month for the purpose of studying and discussing the steel-casting problems before the organization.

Ruhrstahl Annener Gusstahlwerke

The Annen works was relatively small prior to 1939. During the war years the works was expanded tremendously, so that in 1944 a total of 5,000 workers was employed, of which 1,500 were in the foundry. The remaining employees were distributed between the machine shops, forge shops, and maintenance, yard, and office personnel. Workmen in the pattern shop were 105, and the laboratory staff consisted of 130 employees. The buildings were completed in 1942, but at the time of the visit by the writers (July 17 to 20) not all the equipment desired had been obtained. Executives of the Annen works interrogated were:

Dr. H. W. Balster, technical assistant to the executive vice president;
Dr. Hubert Juretzek, technical director, Annen Works;
G. V. Schmidt, foundry superintendent; and
H. Lindner, salés manager, Annen Works.

Production

Comparison of statistics of production during and prior to the was was not feasible owing to the large increase in plant capacity during 1939 to 1944. The average production in 1944 was approximately 5,000 tons per month of liquid electric steel, of which 3,200 tons were used for steel castings, 1,000 tons for steel ingots (for use at other works), and 800 tons for steel forgings.

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Castings produced varied in size and weight from die blocks of 15 tons pouring weight down to aircraft castings weighing a few pounds. Various classifications of castings were produced at the Annen Works, as follows:

1. Die blocks 5 to 15 tons gross weight.
2. Marine castings: U-boat covers, Diesel-engine parts, exhaust-gas housings, pump impellers, submarine pumps.
3. Tractor and automotive castings, including coal-gas generators for passenger cars to operate at 700° C. (1,292° F.), the composition being 0.3 percent carbon, 3 percent chromium, and 3 percent silicon.
4. Power castings: Turbines, valves, and fittings.
5. Refinery castings: Return bends and synthetic gasoline refinery castings.
6. Corrosion and heat-resistent castings: Pumps, turbines, fittings of high-alloy steels for chemical plants.
7. Armor castings for tanks, turret front pieces, bearing housings, and ventilators.
8. Tank castings: Track shoes, sprockets.
9. Aircraft castings: Cylinder barrels, casings, bearing blocks, brackets and covers, fork pieces, strut castings, wheel setments and axel shanks, fittings and lever parts, propeller hubs, etc.

About 1,300 tons per month of liquid steel was produced for aircraft, yielding about 200 tons per month of finished castings. Approximately 1,000 tons of liquid steel per month was used for marine applications, including submarines, yielding approximately 550 tons per month of finished castings. The production of tank track shoes required about 900 tons of liquid steel per month to produce about 460 tons of castings. Approximately 40 tons per month of heat- and corrosion-resistant steel was produced from 80 tons of liquid steel. The small yield of finished aircraft castings was due to the rejection of castings for small defects of various types and the liberal use of risers. It was stated that the Annon plant made approximately 50 percent of all aircraft castings produced in Germany.

Steel Making

The steel-melting furnaces used for casting production were as follows:

1 Brown-Boverie electric arc furnace of 2-ton capacity.
2 Brown-Boveri electric arc furnaces of 6-ton capacity.
2 Stein-Roubaix electric arc furnaces of 8-ton capacity.
2 Brown-Boveri electric arc furnaces of 14-ton capacity.
1 high-frequency (150-kw.) induction furnace of 800-pounds capacity.
2 high-frequency (250-kw.) induction furnaces of 1,300-pounds capacity.

The Brown-Boveri furnaces were so constructed that the roof lifted, and then the furnace was rolled out from under the roof for the purpose of top charging. The operation of moving the furnace required disconnection of water-cooling lines to the furnace. The Stein-Roubaix furnaces were stationary, with a removable roof. The electric furnaces were basic-lined, whereas the induction furnaces contained acid linings.

The lining for the basic furnaces consisted of three courses of magnesite brick laid on the pan with 1-1/2 courses of magnesite brick on the side walls up to above the slag line. From the slag line to the top of the furnace shell one-half course of magnesite brick was used. A rammed monolithic lining was laid on the magnesite brick. This lining consisted of crushed dolomite (1/2 inch diameter to fines) mixed with 8 to 10 percent tar. Bottoms approximately 400 mm. (16 inches) thick are constructed in the 8-ton furnaces. The side walls are also constructed of rammed dolomite to a thickness of 10 to 12 inches. As many as 1,400 heats could be obtained from one hearth lining. However, a life of 1,000 heats was considered normal. The average life of the side walls was 80 heats. A minimum of 40 heats per lining was experienced for aircraft castings produced in the 6-ton furnaces. This condition resulted from the high temperatures required for pouring aircraft castings owing to the necessity for thin sections.

The furnace tops were lined with silica brick. No special shapes were used except those forming the electrode openings. The bricks were laid in rows across the top and not circumferentially, as is the normal American practice. Average roof life was approximately 100 heats.

The induction furnaces were lined with quartzite (96 percent SiO_2) and 10 percent borax (B_2O_3). The lining was rammed dry in forms. As few as 10 to 12 heats per lining life were obtained in the production of high-chromium (10 to 30 percent) steel heats. Approximately 100 to 140 heats per lining could be obtained for low-alloy steel. The furnace lips were made up in kaolin clay.

Electrodes were of the Soderberg type made by the Annen Works. Electrodes for the 6-ton furnaces were 16 inches in diameter and 6 feet long. Considerable difficulty caused by breakage was experienced.

The electric-arc furnaces were made ready for steel melting by charging coke, setting the top in place, and arcing on the coke for about 8 hours. Only the surface layer of the dolomite was fused. The coke was raked out, the furnace charged with steel scrap, and the heat started. In tables 3 and 4 are given heat logs of typical low-alloy steels. It is the practice to use high voltage during the melt-down time and low voltage thereafter to finishing time. It will be noted from the table that two partial and one complete removal of oxidizing slags are recorded. These operations are necessary because of the desire to remove as much of the phosphorus content as possible.

No attention was given to slag analysis or slag control. It was the belief of the company officials that the composition of the slag was as follows:

	Oxidizing slag, percent	Refining slag, percent
FeO	15	Trace
MnO	8	-
CaO	50	65
MgO	10	12
SiO_2	Balance	Balance

TABLE 3. - Heat log of 6-ton basic electric furnace

Desired analysis: 0.35-0.40% C; 0.30-0.35% Si; 0.50-0.70% Mn
1.20-1.40% Cr; 0.15-0.20% V.

Time	Sample	Remarks	Analysis C	Mn	P	Cr	S
0.00		Started in high voltage.					
1.40		20 lb./ton iron ore; 20 lb./ton limestone; 3 lb./ton fluorspar.					
2.00	1	Charge melted Switching over to low voltage	0.50	0.40	0.045	0.25	0.104
2.05		1st slagging 4 lb./ton iron ore; 10 lb./ton limestone; 2 lb./ton fluorspar.					
2.25		Heavy boiling					
2.45	2	2d slagging 4 lb./ton iron ore; 10 lb./ton limestone;	.40	.30	.020	-	-
3.15	3		.20	.25	.015	.20	-
3.20		3d slagging, very thorough limestone, 4% of total charge 0.4 lb./ton coke; 4 lb./ton Mn (5 lb./ton 80% ferromang.) 4 lb./ton Cr (6-1/2 lb./ton 60% ferrochrom.)					
3.40		Slag mix brought up to ratio 20-4-3 per ton of steel, or 40 lb./ton limestone, 8 lb./ton fluorspar 6 lb./ton coke					
3.50		2 lb./ton calcium silicon 0.4 lb./ton coke.					
4.00		Slag melted 4 lb./ton Si (8lb./ton ferrosilicon)					
4.10	4	Slag deoxidized 0.4 kg. coke; 20 lb./ton Cr (33-1/2 lb. ferrochrom) 0.2 lb./ton coke	.34	.45	-	.40	-
4.45	5	 0.2 lb./ton coke 3.0 lb./ton Mn (4 lb./ton 80% ferro Mn) 1.8 lb./ton V	.37	.45	-	1.30	.008
5.15		3 lb./ton Si (6 lb./ton Fe-Si)					
5.25		1.2 kg/ton ingot alum (99% Al) 0.2 kg/ton coke					
5.35		tapped					

TABLE 4. - Heat log of 8-ton basic electric furnace, Annener Gusstahlwerke

Charge: 17,000 lb. steel scrap
200 lb. ferromanganese (15% Mn)
17,200

Time	Remarks	Analysis, percent C	Mn	P
1.15	Power on			
1.40-1.55	Electrode changed			
3.25	Melting completed			
3.30	1st sample	0.65	0.43	0.04
3.35	240 lb. limestone; 300 lb. iron ore			
3.50	160 lb. limestone; 200 lb. iron ore			
4.10	Slag removed.			
4.20	240 lb. limestone; 300 lb. iron ore			
4.35	160 lb. limestone; 100 lb. iron ore			
4.50	2d sample.	.34	.20	
5.15	Slag removed.			
5.25	200 lb. limestone; 300 lb. iron ore			
5.40	3d sample.	.095	.15	
6.00	200 lb. pig iron			
6.10	100 lb. pig iron			
6.30	Slag removed			
6.40	360 lb. limestone; 100 lb. fluorspar			
6.45	30 lb. sand; 30 lb. coke 50 lb. FeSi (75% Si)			
7.10	4th sample.	.21	1.28	
7.20	5th sample.	.23	1.34	
7.30	36 lb. FeMn (75% Mn)			
7.35	50 lb. FeSi (75% Si)			
7.45	32 lb. FeV (54% V)			
7.55	8 lb. Al-Si-Cal.			
	Tapped.			

Specification, percent:	C	Mn	Si	P	V
	0.25	1.40	0.40	0.02	0.10
	.30	1.60			

Current consumption: 950 kw.-hr./ton.

The melters are instructed to produce a white, disintegrating, refining slag, which was maintained for an hour to 1-1/4 hours to permit sulfur reduction. A general rule normally followed was that if the finishing carbon content was to be 0.20 percent or under, pulverized calcium-silicon was added to the slag to bring about reducing conditions. If the finishing carbon content is over 0.20 percent, pulverized coke is used. In some cases fine-particle aluminum was used to produce a reducing slag. This practice was discontinued because of the high cost of aluminum powder. Brown finishing slags were not used, because it was claimed that owing to a need for high-temperature metal for aircraft castings a carbon pick-up resulted when the metal was tapped in the ladle if brown finishing slags were used. Finishing slags consisted of 4 to 6 percent of the weight of the steel.

It was the plan to add all deoxidizers to the furnace. The manganese was added ahead of the silicon, which was followed by the addition of 1-1/4 pounds of aluminum per ton. The aluminum addition was made 10 minutes before tapping. If upon tapping it appeared, through visual observation, that the heat might result in porous castings, an additional amount of aluminum was added to the hand shanks or the pouring ladles. The aluminum was added in small pellets of 5 to 10 grams. No record was made of the quantity of aluminum added to the ladles. Also, no record or study was made as to the residual content of aluminum in the finished castings. The aluminum was added solely to prevent porosity and not for grain-size control. Control of grain size for steel castings was not known in Germany, according to technical officials.

In the control of porosity, special effort was made to assure that slag materials were dry. Limestone is kept in a dry place, and ferrosilicon is heated to 600° to 700° C. (1,022° to 1,292° F.) to remove hydrogen.

The steel is tapped into the ladles over long (6- to 8-foot) furnace spouts. No slag traps were provided. The spouts are lined with silica brick coated with clay. The large bottom-pour ladles are lined with chamotte brick, and the hand ladles are lined with chamotte molding material. Ladles are prefired.

The induction-furnace practice consists of melting down high-grade scrap and using broken glass for slag. The slag weight is approximately 2 percent. Melting time is approximately 90 minutes.

Molding Facilities

Casting production was organized into four separate foundries. In shop 1, cylinders for the air-cooled radial aero engine were produced centrifugally. Crankcase section castings also were produced centrifugally. In this foundry there were also produced miscellaneous castings for tanks, submarines, and die castings.

In shop 2, high-alloy steel castings were made. Foundry 3 was used for mass production of tank track shoes, and in foundry 4 aircraft castings were made. All four foundries contained but little mechanical handling equipment. The few molding machines available were of the jolt turn-over type. Nine core-blowing machines and six core-rod machines of old design were installed in the tank-track show shop. In this shop there were also a few roller conveyors to assist in mass production of track castings. There was no modern sand-reclamation equipment, and sand-conveying equipment was not extensive. Most of the cement-bonded sand was transported to the molding floor in buckets by cranes.

Flask equipment for the most part was heavy, even for small flasks. In most cases cement molds were made in flasks; only a few cement molds were laid out for pouring without flasks. The shake-out equipment was not

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ventilated, but an inadequate attempt was made to ventilate the grinding machines. Shot blasting was carried on in rooms. It was evident that a large amount of manual labor was necessary to maintain the rate of production established by the plant. Also, since the castings were of fair quality, good workmanship and close control were necessary. A complete machine shop containing a full complement of modern lathes, milling machines, planers, etc., was available for machining castings. Approximately 70 percent of all the aircraft castings were semifinished, machined at the works. Four types of molding practices were followed: (1) Cement molding, (2) green-sand molding, (3) dextrine sand, and (4) chamotte.

Cement Molding Sand

The Ruhrstahl Company was the leading foundry organization in Germany in the use of cement-molding sand practice. Such a degree of proficiency had been reached by the company in this type of molding that they had instructed a number of other German steel foundries in the technique. The following reasons were given for the advantages of cement molding: (1) Good-quality molds for steel castings could be made by foreign unskilled laborers without the use of high-class German workmen; (2) oil is not required for molding sands and cores; (3) production could be facilitated, and at the same time molding costs could be lowered. A reduction in molding labor costs of 25 percent and cleaning costs of 40 percent was effected. It is interesting to note that the first cement molding process used in Germany was carried on at the Bochumer Verein in 1941. The Ruhrstahl Company became interested in the process in 1943 because there was a lack of good core oils. The I. C. Farben Industrie was asked to work out a substitute for core oils, and suggested the use of cement, Alkylin, and sand as the most promising substitute. After a year of experimental study, Annener Gusstahlwerke was ready to start production work in the spring of 1944.

Prior to the adoption of the cement-molding method, Annener used an asphalt-bonded sand. Castings of good surfaces were obtained, according to the company officials, but rejections owing to hot tears were high for intricately shaped castings. Another disadvantage besides that of the low collapsibility was that the molds must be baked at 300° C. (572° F.), and during the baking, and later during pouring, very obnoxious fumes were given off. In contrast to this type of sand molds, cement-sand molds did not produce gases upon being poured, they required no baking or drying, and they caused no hot tears because they have good collapsibility.

Cement molding-sand mixtures without the use of Alkylin can be used at the lowest cost. Alkylin is the trade name of a water-soluble cellulose-ether solution, the ash content of which approximately 3 percent, composed of 44 percent Alkalies, 27 percent quartz, 3 percent iron oxide, 12 percent clay, 6 percent lime, 1.5 percent magnesia, and 4.5 percent sulfuric acid residue.

Experimental work with Alkylin solution added to cement mold sand has proved the following advantages over the simplified cement-sand mixtures: (1) Increased green strength, (2) increased collapsibility of both molds and cores after pouring, (3) superior casting finish and thus fewer cleaning difficulties, and (4) greater degree of workability.

Silica sand of 0.2 to 0.6 mm. grain size, as shown in table 5, was found to be best for cement molding.

TABLE 5. - "Silver" sand (90 percent SiO_2)

Grain size, mm.	Percent
0.6 -1.00	0.2
.3 - .60	22.6
.2 - .30	65.2
.1 - .20	11.2
.06- .10	.3
-.06	.2
	99.7

Various cement, Alkylin, and water mixtures were studied, and it was observed that with a small percentage of Alkylin the optimum dry-strength values were unduly retarded and were not retained for any length of time. Also high-moisture conditions retarded the development of maximum dry-strength properties. Best results were obtained from sand mixtures of 10 to 15 percent cement, 0.5 to 1.0 percent Alkylin, and 6 to 8 percent water. As the Alkylin was prepared for molding conditions as a water solution, the moisture content of the sand resulted from the water added to the sand plus the water present in the Alkylin solution. Normally, a 1:7 solution of Alkylin and water was used, but as the Alkylin supply became restricted, a ratio of 1"14 was used. Tests made on the conservative ratio of 1:14 was used. Tests made on the conservative ratio of 1:14 indicated good production results.

Alkylin increases compression and transverse strength but reduces permeability considerably, as is shown by table 6.

TABLE 6. - Effect of Alkylin upon the properties of cement-sand

	Permeability, $M_3/Cm_3/mm$	Compression strength, Kg/Cm_2	Transverse strength, Kg/Cm_2	Water, percent
Without Alkylin	122	0.120	0.020	7.6
With Alkylin	58	.200	.060	7.4

Setting of the cement was accelerated through the use of calcium chloride ($Ca Cl_2$), which was added to the mix in amounts not to exceed 0.5 percent of the weight of the mix. Engineers at the Annen Works were advised early in March 1945 by Professor Eitel, director of the Kaiser Wilhelm Institut für Silikatforschung, that addition of more than 1 percent of $CaCl_2$ was necessary before it would react advantageously as an accelerator for the setting of cement.

Burnt-on sand and metal penetration are the most important defects in the use of cement molding sand. Professor Eitel investigated burnt-on sand aread and found them to be essentially an enamel consisting of easily fusible iron silicates (fusion temperature of about 2,100° F.). It was the experience of the Annen Works that Alkylin additions reduced the number of burning-on spots. Professor Eitel is of the opinion, however, that alkylin containing an alkali would reduce the fusion point of the sand mixture, and, therefore, he recommends that Alkylin be replaced by sulfite lye.

Researches by Professor Eitel indicated that burnt-on sand also occurred when cement of the highest quality was used. He, therefore, proposed the use of "Sorel" cement, a mixture of magnesia (MgO) and magnesium chloride ($MgCl_2$), because this material has a high fusion temperature, with the result that the burnt-on effect would be less. The composition of this mixture is 100 parts by weight of quartz sand, 4.5 parts magnesia, and 6 parts magnesium chloride (German Patent No. 740735).

At the Annen Works the cement-sand mixture is prepared at the various molding floors, so that it is not necessary to store the sand, and fresh mixtures may be used shortly after they have been prepared. Maximum storing of cement-sand was limited to 1 hour, though it was possible to hold the cement-sand for as much as 6 hours before it was unworkable. Difficulties were encountered in winter, when the stored cement-sand cooled too much, producing a crumbly sand that was difficult to ram properly. In winter, also, molds were dired at approximately 100° C. (212° F.) for 2 to 4 hours. Normally, the molds were permitted to air-dry 24 or more hours. In summer, when floor space was insufficient, the molds were also dried at 100° C. (212° F.). Drying was accomplished by moving portable electric ovens, shaped like bell jars, to the molds in position on the pouring floor.

The facing sand need not be thicker than 50 mm. (2 inches), but for light-walled castings the thickness of the facing sand may be much less than this. Mold washes were not used for cement-sand molds.

Cement-bonded sand may be reclaimed 100 percent for re-use as facing sand and as backing sand. However, at the Annen Works, because of the lack of proper processing equipment, only 10 percent of the shake-out sand was reclaimed, 90 percent being discarded.

The change-over from chamotte to cement sand for use on large castings was still in the experimental stage at the time the plant was closed in February 1945. The problem of the fusion of the cement-bonded sand to the surface of the casting was not completely solved, but it was the hope of the management that this problem could be solved through the cooperation of Professor Eitel. They were anxious to make the change, as they believed that there was less possibility of hot tearing when cement-bonded sand was used for casting than when chamotte was used.

Small and some medium-size castings, when molded in cement, were stripped of their flasks when the molds were placed on the drying or pouring floor. The dried molds were then placed in portable clamping devices and poured.

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Most of the cement-bonded molds were molded in flasks. When the larger flasks were used, the backing sand consisted of old cement sand that had been crushed by passing it through rolls. Since the molds made of chamotte are also shaken out in the same place as the cement-bonded molds, the backing sand may be a mixture of used cement and chamotte sands.

The cement core sand is of the same composition and fineness as the molding sand. The center portion of the larger cores may be filled with a mixture of used chamotte and cement sands or with ashes, cinders, or sawdust.

It was reported by the Annen plant officials that it was possible to produce cement-bonded cores by core blowing and that cores were made for the 10-cm. antipersonnel bombs by such a procedure. A rubber-lined core box was used for longer core-box life.

An indication of the extent to which cement sand is used is given in tables 7 and 8.

TABLE 7. - Extent of cement molding as used at Ruhrstahl Annener Gusstahlwerk

Month and year	Tons of liquid steel poured in cement molds for the four foundries	Percentage of the total steel production for castings
August 1944	962	28
September 1944	998	37
October 1944	1,086	34
November 1944	1,020	35
December 1944	666	27
February 1945	756	43

TABLE 8. - Production of steel castings by the cement-molding process for all Ruhrstahl plants

Plant	Liquid steel, tons	Percent of total poured into sand molds, June 1944	Percent saving in working type by use of cement	
			Molding	Precleaning
Hattingen	2,300	13	-	10 to 30
Gelsenkirchen	2,600	8	25 to 30	30
Oberkassel	2,000	5.5	20 to 25	0 to 40
Annen	3,800	25.5	25	60

The tonnage of liquid steel poured in the various types of sand as of February 1945 is as follows:

	Liquid steel Tons	Liquid steel Percent
Cement sand	1,500	43.1
Dextrine sand, dry	700	20.3
Dextrine sand, green	1,000	28.9
Chamotte	250	7.7
	3,450	100.0

Green Sand

A dextrine sand was used for green-sand molding. All the track links for tanks were produced in this sand. Early in the war, the dextrine sand was mixed as follows:

94 percent silver sand (washed quartz sand)
3 percent clay
3 percent Dextrine

The dextrine consisted of:

20 to 40 percent dextrine (starch from potatoes)
30 to 40 percent sulfite lye (powder)
20 to 50 percent clay or bentonite.

The original sand mix was changed owing to the lack of clay. The clay was replaced partly, and finally entirely, by "yellow sand" which is a natural bonded sand containing approximately 21 percent clay of the following grain:

Grain size	Percent
0.3 to 0.6	0.2
.2 to .3	.6
.1 to .2	45.0
.06 to .1	25.0
Less than 0.06	29.0
	99.8

In 1942 and 1945 the facing sand for green-sand molding consisted of the following:

	Percent
Silver sand	58
Yellow sand	17
Heap sand	13
Fire clay	6
Sea coal	6

Late in 1943 the government forced the plant to discontinue the use of facing sand. The sand was then reconditioned by the addition of 8 to 10 percent Geko, which often was called bentonite, as it was considered a substitute for bentonite. Geko was prepared by water flotation and chemical treatment of ordinary clay to make a high-test clay. If new sand was required to supplement the supply, a mixture of 75 percent silver sand and 25 percent yellow sand was added. The green sand was tempered according to feel to approximately 4 percent moisture. Green-sand molds were poured a few hours after molding or were permitted to air-dry overnight. For larger castings, they were oven-dried. Cores made of the dextrine sand were water-washed and dried at 150° C. (302° F.). The dextrine molds were not coated with a wash.

Testing of molding materials consisted in testing the individual components of the mixtures, such as testing grain size of sands, analyses and ash content of binders, viscosity test of core oils, and setting qualities of cement. The prepared sands were said to be tested daily for moisture. Some tests were made on the hot strength of the sand mixtures.

All the cores for the track links for tanks were produced on nine core-blowing machines and six stock core machines. The sand mixture for these core machines was as follows:

	Core blowing, percent	Stock cores, percent
Silver sand	84.6	43.6
Yellow sand	7.7	43.6
K 1 core oil	4.5	6.6
Sulfite lye	3.2	6.2
Moisture	5 - 6	6 - 7

The cores were oven-baked at 250° C. (482° F.). Cores were also blown with cement sand. These cores were for small (10-cm.) antipersonnel bombs. Rubber-lined core boxes were used on the core-blowing machines. The cores produced on the machines were checked, after baking, to tolerance gages, and all warped cores were rejected. The machines produced the cores to very close tolerances. This was necessary, as it was the desire to machine the track shoes as little as possible.

Chamotte

The larger castings were produced in chamotte. A complete description of the chamotte molding materials is given under Part 2, Bochumer Verein. It was the desire of the plant officials to make as many of the large molds in cement sand as possible.

Pouring

No outstanding practices were carried on in connection with pouring castings. No research had been conducted on pouring speeds or rate of rise of metal in the mold. An attempt was made to keep the sprue full of steel. Considerable use had been made of the open-side-down gate, or French gate, leading into risers or heavy vertical sections. This type of gate was especially popular for cement-sand molds. In positions where streams of metal impinged on mold or cores it was the practice to use chamotte inserts regardless of the type of the mold, that is, whether it was cement or dextrine.

It was the plan of the management to produce castings to directional solidification requirements. Some few studies had been made of temperature gradients existing in production castings. An attempt was made to gate into risers whenever possible. Risers were massive and tall, and in most cases the yield was seldom over 50 percent. A carbonaceous exothermic material was used on most risers. It was believed by company engineers that the material, known as Ca-Si, which they were using contained aluminum and magnesium powder in addition to carbon. It was the plan to place the Ca-Si on the riser and then cover it with a layer of sand to keep the exothermic material from flashing in the air and losing heat, which otherwise would be transferred to the steel in the riser. The company engineers claimed that the use of the exothermic material made the temperature of the steel so high that unit shrinkage of the metal in the riser occurred, leaving no or little pipe. No evidence of this was observed.

For large risers, electric-arc equipment is available. The equipment manufactured by Bomecke & Borghardt, Witten, consists of one, two, or three electrodes, depending on the size of the riser to be heated. The electrodes are approximately 3 to 4 inches in diameter, and an arc is struck on the metal as soon as the risers are filled.

Centrifugal Casting

Gun liners, tubes, cylinder liners, sleeves, crankcases, and propeller hubs were cast centrifugally. Three types of machines were available: (1) Water-cooled, large, horizontal machines, (2) compressed-air, horizontal machines, and (3) turntable, vertical-spindle machines. Nearly all of the production castings were being made on types 1 and 2. These machines and their development are discussed in Part 4, Deutsche Edelstahlwerke.

Though the plant was not operating, a special exhibition run was made on the two horizontal machines. Cylinder liners weighing about 40 pounds were produced in a cast-iron mold. The mold was given a graphite-clay coating prior to pouring. The life of the mold was approximately 500 liners. Induction-furnace steel was tapped into a hand ladle according to a volume measure. The mold is rotated on the machine rolls. Timing of operations of the investigators showed that 50 seconds were required to transport the metal from the furnace to the machines, during which time the machines were coming up to 800 r.p.m.; 10 seconds were required to pour the casting. The casting rotated 1 minute and 15 seconds after pouring before it was stopped and rejected from the machine. Rotation is continued until the casting freezes. The operator watches the color of the inside of the tube and uses color change as an indication of solidification. The complete operation cycle requires 2-1/4 minutes. Normally, when three machines are in operation, the time cycle is 1 minute 20 seconds, 45 seconds being allowed for solidification of the casting.

A tube of 10.3 feet, 232-mm. outside diameter (9.3 inches), and 165-mm. inside diameter (6.6 inches) was made in the exhibition run. The mold was rotated at about 1,400 r.p.m., and the tube containing washed sand of 0.2 to 0.6 grain size was run into the mold and rotated, spilling the sand in the mold to a depth of about 2 mm. The tube was withdrawn, the machine tilted 5° downward from the pouring basin, and a weighed amount of steel was run into the tube. Pouring time was 35 seconds, and total spinning time, including the pouring time, was 4 minutes. The total time from pouring to the removal of the tube was 8-1/2 minutes. It was claimed that the average time for a complete cycle on production bases was 12 minutes.

A wheel casting for tanks was studied in several ways to find the best method of producing a sound casting. The best static casting produced after quality-yield considerations was 340 pounds total weight in the as-cast condition. By casting the wheel centrifugally, a satisfactory casting was produced at 180 pounds. The machined, finished casting weighed 100 pounds. Considerable saving was made by casting these wheels on a vertical-spindle, platform-type, centrifugal casting machine.

Heat Treatment

Castings are annealed or normalized according to the property required. All armor castings are quenched and tempered. Whether the quenching liquid is water or oil depends on specifications prepared by the Government on carbon and alloy content and on casting design. Time quenching is not practiced. All castings are quenched either cold or to a temperature not exceeding 200° C. (392° F.). All carbon cast steels exceeding 0.35 percent carbon are oil-quenched and under 0.35 percent they are water-quenched. The dividing line on alloy steels occurs at 0.30 percent carbon. Certain massive castings, such as cast forge die blocks of 0.50 percent carbon, are water-quenched. Removal of castings from the oil quench depends upon whether or not the oil flashes and burns. If it does so, the casting is returned to the quench and is permitted to stay there until, upon its removal, the oil does not flash. No attention is given to duration of quench in water quenching.

The two oil tanks were 13 by 16 by 20 feet, and the water tank was 20 by 13 by 20 feet. Circulation was provided. The requirements for the oil quench were that 10 tons of castings could be cooled in 1 hour from 1,650° to 300° F. without raising the temperature of the oil. The heating furnaces from which quenching is carried on hold 20 to 30 tons of castings. A tray holding 3 to 5 tons of castings is quenched at one time.

Cleaning

Shot-blasting of castings prior to heat treatment and following heat treatment is the normal operation. Aircraft castings are sand-blasted because it was the belief that shot blasting peened over surface defects such as cracks. All the cast skin was removed on aircraft castings by either grinding or rough machining prior to the use of a hot-oil test for the disclosure of cracks. All aircraft castings must be magnetic-particle tested prior to welding. If defects are present, they must be inspected magnetically after the defect has been removed and again after welding. Radiography is used only on occasional castings as a spot-check of quality.

Welding

Both electric-arc and atomic hydrogen welding are used. Castings are not preheated prior to welding unless the casting is large and an important one. Welding procedure in this case consists of preheating the casting to 300° C. (572° F.), either by local preheat or heating the entire casting, and then laying a weld metal bead; the bead is then peened and ground smooth prior to laying another bead.

All aircraft castings are electric-welded. Four types of electrodes are used: (1) 38-45 kg./sq.mm. (54,000-64,000 psi), (2) 50-55 kg./sq. mm.

(71,000-73,000 psi), (3) 90-100 kg./sq. mm. (128,000-142,000 psi), and (4) Austanitic.

A popular welding rod consisted of 1 percent chromium and 0.5 percent molybdenum. It was the plan, wherever possible, to produce a weld the strength of which would equal the strength of the casting.

For armor castings only there was a restriction that the maximum defect that could be welded was 15 percent of the wall thickness. Only defects on the outside surface could be welded. Inside surfaces could not be welded, as it was felt that the weld metal would come out as a slug if heavy impacts to the armor were experienced. Such slugs might injure personnel or tank parts.

On large castings where the defect was extensive the casting designer was asked to look at the casting at the place where the defect had been removed and to calculate if the remaining wall section would give the proper design strengths. If so, the weld could be made, and the entire weld could then be considered as a factor of safety.

Atomic hydrogen welding was liked very much because it was claimed that results superior to those from electric-arc welding could be obtained with unskilled workmen. Copper-coated bare welding rods were used with atomic hydrogen welding. Approximately 80 percent of all welding was atomic hydrogen welding. For the usual run of castings, all defects could be welded with no limitations; in fact, the entire cross section could be rebuilt by welding. All that was necessary was that a red mark indicating the position of the weld was required on the casting surface. Even this requirement was not complied with at all times. The welders were approved by the company. There were no welders approval tests by the Government or inspecting agencies.

Inspection

Aircraft Ministry had its own inspections for aircraft steel castings. All foundries producing aircraft castings had to be approved by an agency (R.D.L.I.) of the Aircraft Ministry. A foundry would contact or be contacted by an aircraft manufacturer for the production of a certain casting. Trial castings would then be prepared by the foundry and inspected by the R.D.L.I. All tests are made at the foundry under supervision of the inspector. Approval of the foundry for that particular design would then be forthcoming if warranted. Every design had to be approved (3 weeks to 4 months). The manufacturers of aircraft checked and tested castings and design. Castings were selected for loading tests. Two classes of tests were used - Class A, a full loading test, and Class B, Brinell tests only. Designers used identical designs for castings and forgings. However, all forgings were redesigned if they were to be made as castings, so that they would be castable. The officials advised that there were no records of casting failure in aircraft.

The major development of aircraft castings took place mostly between the aircraft manufacturers and the foundries. During the development of a new design, the foundry bore all expenses. In 1943 the Government issued instructions that 2 percent of all steel construction in aircraft must be steel castings.

Blue prints for aircraft castings and nearly all other steel castings showed the position of the test coupon and areas where welding is restricted, if such is required. Test coupons were 3/4 to 2-1/2 inches thick. No allowance for lower mechanical properties was made for the heavier section. Brinell testing of all aircraft castings was required, and the position of testing was selected by the inspection service. Impact testing was not specified for aircraft castings, but impact tests were made for information purposes. A hot-oil test of castings was made in the foundry as an inspection for cracks. The specifications for aircraft castings are given in detail in Appendix I.

Defects

It was believed by the technical personnel that porposity was largely caused by hydrogen and/or nitrogen, but it had no proof of the matter. Flakes are occasionally found in light sections and were definitely attributed to the use of moist lime or wet limestone. It was also believed that all types of poor structure, such as the concoidal type, were due to improper heat treatment and not to gas or inclusion. It was stated that when a film formed early over the molten metal in the spoon test, addition of 2 to 3 pounds of aluminum per ton would correct the condition.

A detailed rejection analysis for the various foundries is given in tables 9 and 10.

TABLE 9. - Detailed rejection analysis for February 1945, Annener Gusstahlwerke

	Foundry 1, percent	Foundry 2, percent	Foundry 3, percent	Foundry 4, percent[1]
Sand inclusions	26.90	24.30	6.98	2.41
Scab	4.17	3.80	-	-
Shrinkage	-	-	1.50	-
Shifts	1.24	0.89	4.70	17.00
Defective cores	1.43	1.03	8.10	5.50
Slag		-	2.30	-
Porosity	29.65	29.60	-	-
Blow holes	-	-	0.40	10.20
Tolerances	-	0.78	10.04	12.10
Misruns	1.63	3.20	31.33	42.85
Hot tears	-	-	-	-
Poor torch cutting	-	-	1.36	-
Cracks	-	-	3.44	4.90
Broken	-	-	-	5.04
Oilboil test	34.30	33.30	1.80	-
Miscellaneous	.68	3.10	1.47	-
	100.00	100.00	100.00	100.00
Total rejection, pounds	46,078	64,192	15,096	110,030
Percent of total	19	27	7	47

[1] Chain links for tanks only.

TABLE 10. - Ruhrstahl Aktiengesellschaft
Annener Gusstahlwerke

Scrap report of steel aircraft castings

Percentage of defective castings:

	Kg.	Percent[1]
Melting	3,155.5	2.20
Foundry	24,354.0	16.80
Cutting	204.0	.10
Heat treat	677.6	.50
Rough clean	4,213.6	2.90
Finish clean	694.8	.50
Machine shop	411.0	.30
Dimensions	3,295.0	.20
Miscellaneous	482.0	.30
	34,192.7	25.80

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[1] Of monthly production.

Cause of defects:

Melting:	207 pieces		
Foundry:	1,881 pieces, of which	483	sand holes
		694	shrinks
		152	shifts
		72	cold shuts
		106	blown; porosity
		116	hot tears
		258	miscellaneous
Cut off:	37 pieces		
Heat treat:	104 pieces	42	heat cracks
		48	distortion
		14	miscellaneous
Machine shop:	450 pieces	192	milling
		41	drilling
		197	turning
		18	planing
		2	miscellaneous
Cleaning:	241 pieces		
Inspection, etc.			
Total	2,920		

The following is also included as to rejections on various types of castings:

Type	Aircraft, percent	Marine and miscellaneous, percent	Tank treads, percent
Sand and slag	6	3-5	4-5
Improper analysis	1-2	0.5	-
Removal of risers	1-2	-	-
Shifts and misplaced cores	1-2	0.5	1.0
Hot tears and shrinkage...	3	1-2	1.0
Breakage on shake-out	-	-	3-4
Machining rejections[1] ...	6-8	-	-
	18-22	5-7	9-10

[1] 75 percent of output finished machined.

Mechanical Properties

The chemical analyses, heat treatment, properties, and use of various grades of steel castings produced at the Ruhrstahl Annener Works is given in Appendix 2. These are not only representative for the Ruhrstahl Company but for the higher-grade German steel-casting foundries, In many cases the compositions, heat treatments, and properties were specified by the German Government.

Research studies on the addition of beryllium to cast steel, armor-steel composition and properties, and the specifications for steel castings for heat-resisting applications are presented in Appendixes 3, 4, and 5.

Ruhrstahl Stahlwerke Krieger, Oberkassel

Stahlwerk Krieger at Oberkassel is a part of the Ruhrstahl A. G. The foundry was built in 1900 and contains its own machine shop and pattern shop. It was bombed in August 1942 but was only slightly damaged and continued operation until February 28, 1945. On March 1, 1945, United States troops entered the area. It is believed by the management that the plant is only 5 percent damaged. A. Ritter, foundry superintendent, was interrogated.

The melting units installed in the plant were three 25-ton basic open-hearth furnaces, one 8-ton basic electric, one 6-ton basic electric, and one 2-ton basic electric furnace. Monthly production was approximately 2,000 tons of liquid steel to produce 1,000 tons of steel castings. Approximately 5,000 tons of ingots also were produced. Of the total steel produced for castings, 60 percent was plain carbon steel and 40 percent alloy steel; of the latter, approximately 10 percent was 12 to 14 percent manganese steel.

The 1,000 tons monthly of finished castings included the following main classifications: Armor castings, 200 tons; rolls, 100 tons; ship castings, such as stems, frames, and struts, 100 tons; railroad castings, including driving wheels, trucks, cross heads, bearing housings, etc., 200 tons; miscellaneous castings, including forge-press castings, turbines, rolling-mill castings, gears, etc., 200 tons; 12-14 percent manganese steel castings, 100 tons; and 100 tons of miscellaneous small castings weighing less than 100 pounds each. The largest casting poured was a propeller-shaft bearing support for the Italian liner REX that weighed 80 tons gross weight and 50 tons shipping weight. The smallest castings produced weighed about 20 pounds.

Approximately 320 workmen were employed in the foundry. Approximately 1,000 men were employed at the plant (including, beside the foundry, the machine shop, pattern shop, and ingot departments), of which 250 were Russians, 200 Italians, and 80 French.

Most of the molding was done in chamotte, but 120 to 150 tons per month was molded in cement-bonded sand, and 150 tons per month was produced in dextrine sand. The dextrine sand was mixed as follows:

	Percent
Silver sand (quartz sand)	75
Yellow sand (Ratingen, natural-bonded ...	15
Clay	6.5
Dextrine	3.5
Moisture content	6-8

The dextrine-sand molds were air-dried overnight prior to pouring. Cores were produced in chamotte, cement-bonded sand, dextrine sand, and an oil-dextrine-sand mixture. One interesting development observed was the shaping of vertical cores to be used in outlets in the form of projectiles. This allowed a riser to be placed completely over the outlet to obtain the maximum feeding of the outlet section.

Both oil- and water-quenching of castings was employed. The purchaser usually specified the type of quenching medium desired. Large and medium castings were quenched individually. The 12 to 14 percent manganese steel was tray-quenched in lots of 2 to 3 tons.

Most of the heat treatment consisted of annealing; only 300 tons (armor and high-manganese) of castings were liquid-quenched. A large proportion of these were annealed in removable-roof, pit-type furnaces. In certain cases, when it was desired to accelerate the rate of cooling in these furnaces, cages constructed of iron pipe and connected to compressed-air lines were lowered over the castings, and cool air was circulated around the base of the casting.

Scrap resulting from defective castings was claimed to be only 2 percent. The most common trouble was rejection because of shrinkage cavities. The next most frequent defect was slag and sand inclusions. Very little trouble was experienced from hot tears. Some of the castings seen had very rough surfaces, whereas others were fairly smooth. The castings that caused them the most concern and trouble were stern posts, frames for ships, and turbine housings. Approximately 3 to 5 percent scrap was obtained from manganese steel, owing to hot tears and quench cracks.

For the most part, molding, cleaning, and heat-treating methods were similar to those described for the Annener Works of the company. Steel melting was identical to that described for the Annener Works.

Ruhrstahl Henrichshütte, Hattingen

The Henrichshutte Works of the Ruhrstahl Company contained a steel foundry, an iron foundry, rolling mills, blast furnaces, and coke ovens. Approximately 10,000 workmen were employed, according to Dr. Vogeler, the technical director. This plant is the largest of all the Ruhrstahl works. It was bombed on March 14, 1945, and the damage was considerable. All work stopped on that date. The steel foundry employed 400 to 500 men.

Molten steel for the foundry and the ingot shop was furnished from eight basic open-hearth furnaces (seven 50-ton and one 200-ton) and two 25-ton basic electric furnaces. The steel-making cycle, including charging, for the 50-ton open-hearth furnaces was 14 to 16 hours.

The foundry primarily produced railroad and locomotive castings. The Works was formerly under the management of Henschel & Son and was operated as a part of the Kassel Locomotive Works. The plant was takne over by Ruhrstahl in 1932. Approximately 4,000 tons per month of liquid steel was poured to produce 2,000 tons of castings. Approximately half of the production, or 1,000 tons per month, was produced as railroad and locomotive castings. A specialty of the foundry was the production of pots for annealing wire. Approximately 30 tons of liquid steel per day was poured to produce 350 tons per month of finished pots. The remaining 650 tons per month of castings were miscellaneous rolling-mill and press castings. The largest castings produced were rolling-mill castings of 120 tons finished weight. The smallest castings averaged about 600 pounds.

Very nearly all the steel made was carbon steel. Only a very small percentage of alloy steel was produced, and this was for turret pieces for tanks.

Virtually all castings were molded in chamotte. Several grades of chamotte, as discussed under the Bochumer Verein practice, were used. The annealing pots were produced in cement-bonded sand and consisted of 0.18 to 0.20 percent carbon steel fully annealed.

All sand, mold, and melting practices were virtually identical to those of Ruhrstahl Annener.

Ruhrstahl-Gelsenkirchener Gusstahlwerke

The Gelsenkirchen plant of the Ruhrstahl Company made 2,000 tons of molten steel per month to produce about 1,000 tons of castings. Both basic and acid furnaces were used. The acid furnaces were operated for the production of steel for mine-car and narrow-gage dump-truck wheels. The basic furnaces were used for the production of gears and gear housings of all sizes. The plant was similar in operation to Ruhrstahl Krieger, and the acid practice was like that of Deutsche Eisenwerke at Mülheim and of Krupp at Essen. No outstanding practices were observed.

PART 2. - BOCHUMER VEREIN

The Bochumer Verein Company operates two steel foundries - Bochumer Verein für Gusstahlfabrik at Bochum and Bochumer Verein at Weitmar.

Officials of the Company stated that steel castings were first produced by Bochumer Verein on a commercial scale 80 years ago. It was the opinion of these officials that the Bochumer Verein Company produced the first steel castings made in the world. In 1867, the Company exhibited cast-steel bells weighing as much as 16-1/2 tons at the Paris World Fair.

The company officials interrogated for the two plants were the director, Dr. Schily, Dr. Ammareller, director of research, Mr. Bremer, melting superintendent, A. Heuvers, director of foundries, H. Bergerhoff, Mr. Moller, and A. Sickbert.

Bochumer Verein, Bochum

The foundry at Bochum was housed in one large building of six bays and was in good condition. Four of the bays were used for molding, cleaning, and heat-treating castings, and the other two housed the steel-making furnaces and equipment.

Basic Electric Practice

Two 40-ton, one 15-ton, and one 6-ton Deutsche Maschinenfabrik (DEMAG) furnaces were available for making steel for the manufacture of castings. The larger furnaces also were used for the production of ingots. It was possible to rotate them through 30 degrees. The furnaces moved out from under the roof to permit top charging. They were lined basic. Three courses of magnesite brick were placed on the bottom and one course on the side walls. On top of the brick was rammed dolomite to which had been added 6 percent tar. Total bottom thickness was approximately 20 inches, and the wall thickness was 15 inches. Ground magnesite bonded with clay is molded to form the pouring spout and tap hole. The spouts are formed and repaired before each heat.

Typical heat logs for the 40-, 15-, and 6-ton electric furnaces are given in tables 11, 12, and 13.

During the oxidizing period, a good boil is maintained, resulting in a drop of at least 0.30 percent carbon. All slag-making alloys and ferroalloys are heated before using. Water in burnt lime can be driven out only by heating to 700° C. (1,292° F.).

Typical oxidizing and refining slag analyses are as follows:

	Oxidizing slag, percent	Refining slag, percent
FeO	8-15	Less than 1
MnO	10	Do.
CaO	50	50
SiO_2	10-20	15-20
MgO	2-3	1
CaF	-	15

The normal practice on phosphorus and sulfur control is to reduce phosphorus from 0.035 percent to 0.012 to 0.015 percent and sulfur from 0.030 percent to 0.010 to 0.012 percent. A refining slag of a ratio of 4 lime to fluorspar is used; to this, pulverized coal or pitch coke is added at a rate equivalent to 5 percent of the slag weight. If low-carbon steels are to be made, pulverized ferrosilicon is used in place of the coal. Slag is controlled by visual examination and analysis. The slag color and method of slag disintegration were watched, and the information collected assisted the melters in the preparation of the heats. A rule normally observed was that the finishing slag must contain less than 1 percent total Fe, Mn, and Cr. Heats are tapped under a brown slag only if the quality permits the higher sulfur content. Aluminum is placed in the bottom of the ladle at a rate of about 1 pound per ton, and the heat is tapped upon it. The furnaces are tipped rapidly, so that 2 or 3 tons of steel enter the ladle without slag accompanying it. The residual aluminum content is approximately 0.003 percent.

All ladles except those used for pouring centrifugal castings are bottom-poured. Purchased chamotte bricks are used for lining the ladles. To avoid slag inclusions, no wash was used.

Fluidity tests were not made, because only fairly heavy-walled castings were poured. The thinnest section made was about 2 inches.

Approximately 1,200 tons per month of basic electric steel and 2,000 tons per month of basic hearth steel were poured into castings. Acid steel was not liked because hot tears were common in castings made from it.

An attempt was made to line the 6-ton furnace with a basic roof, but a life of only 12 heats was obtained.

Basic Open-hearth Practice

Four 35-ton Martin furnaces were available for the production of steel for castings. Approximately only one-seventh of the steel made was for castings. Coke-oven gas was used as a fuel. Basic roofs were used on two furnaces with good results; a roof life of 800 to 1,000 heats each was obtained. The bottoms were rammed with dolomite to a depth of 12 inches. One furnace was lined with a Krespi bottom as an experiment. Instrument control on the furnaces was virtually nil. Considerable reliance on the knowledge and experience of the melters and head melters is the normal rule in Germany.

A typical heat lot of the 35-ton basic open-hearth furnace is given in table 14. Slag control consisted of pouring slag pancake tests and observing the color on the fracture surface. The last slag sample taken must not contain more than 10 percent FeO. The chemical determination of FeO in basic slags took only 10 minutes.

Molding Practices

Bochumer Verein, under the direction of Mr. Heuvers, practiced directional solidification of castings for many years. All new designs were reviewed by a committee of three men - the foundry superintendent, foundry foreman, and the foundry technologist - who decided on gating and risering methods in accordance with the principle of inscribed circles laid down by Heuvers. All gates and risers were attached to the casting, and top gating was used whenever possible. The favorite gate for the heavy castings which this company produced was the open-side "French" gate. This was considered to be greatly superior to the step gate. The risers used were for the most part quite high in comparison to their diameter. It was stated by Hauvers that experimental work going forward during the last 2 years has definitely shown that for risers of a diameter less than 1 meter (approximately 40 inches) the 1:1 ratio of diameter to riser height is not sufficient. For example, for risers of 50 mm. (approximately 2 inches) the riser height must be at least 100 mm. (approximately 4 inches) in order to obtain acceptable feeding conditions to produce steel of good mechanical properties directly under the riser. For the most part, it was the rule to have the total weight of the risers equal 60 to 80 percent of the weight of the casting.

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Pouring rates are regulated by attaching a pouring dish or basin to the bottom pour ladle. The opening (diameter) in the pouring basin is usually 15 to 50 mm. (0.6 to 2 inches); for exceptional cases, 50 to 80 mm. (2 to 3.2 inches) is used. The gate system in the mold is constructed to be 50 to 100 mm. (2 to 4 inches) in diameter. By using this arrangement it is not necessary to have pouring cups on each mold.

Bochumer Verein was the first foundry in Germany to use cement molding material. It was the opinion of Heuvers that cement sands were not as good as chamotte for thick-walled, heavy castings; therefore, Bochumer Verein continued to make most molds of chamotte.

The best grade of chamotte contains 35 to 40 percent Al_2O_3 and is produced by the Lungen Company in Erkrath, Rhineland. Chamotte consists of clay calcined at a high temperature and crushed to a maximum particle size of approximately one-fourth inch and finer. This calcined material is then mixed with raw clay for proper binding purposes. The chamotte received by the foundries is ready for use except for the addition of water. Normally, about 5 to 8 percent is added to the chamotte. It is normal practice at most German steel foundries using chamotte (and this holds true for Bochumer Verein) that the purchased chamotte is diluted with other grades of silica sand to produce several grades of molding material known as "Form Masse." At the Bochumer Verein Company four grades of Form Masse are prepared:

Type 1: 100 percent chamotte. Wall sections greater than 100 mm.
Type 2: 75 percent chamotte, 25 percent old sand. Wall sections 75 to 100 mm.
Type 3: 50 percent chamotte, 50 percent old sand. Wall sections 30 to 75 mm.
Type 4: 50 percent chamotte, 25 percent old sand. Wall sections 15 to 30 mm.
Type 5: 25 percent chamotte, 25 percent old sand. Wall sections 10 to 15 mm.

The old sand is shake-out sand that has been remulled and then added to the chamotte. The yellow sand is a fine semibonded silica sand. The facing sand of all molds is 30 to 50 mm., depending on the section thickness. The ratio of permeabilities of the various mixtures is 7:5; 4 for mixtures 1, 3, and 5, respectively.

Only a small percentage of green sand, cement sand, and dextrine sand is used. Consequently, all molds containing sands and chamotte are shaken out at the same place for mulling and retermpering as backing sands.

Castings of thin-wall sections such as submarine motor housings of 7 to 8 mm. (approximately 0.3 inch) are produced in oil-sand cores made from silica sand and core oil. No addisional binder was added. Cores of chamotte are made from a high-grade chamotte and not from Form Masse. Chamotte cores may have centers made of ashes or cinders. Molds and cores are dried at 500° C. (932° F.). If modern recirculating furnaces are available, the drying temperature may be 400° C. (752° F.). If the heating temperature is too high,

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casting surfaces and dimensional tolerances are poor; whereas, if heating is carried on at too low a temperature, the castings may be porous. The molds remain at a temperature of 500° C. (932° F.) for 3 to 6 hours, and the total heating time is 12 to 16 hours.

In preparing the mold, cast-iron blocks are rammed into it in many cases. These blocks are removed shortly after pouring to permit the casting to contract more freely, thus reducing the formation of hot tears.

Cleaning, Testing, and Rejections

The cleaning of castings at Bochumer Verein accounts for about one-third of the total cost of producing castings. Shot blasting is used exclusively. Padding on castings is removed with a cutting torch when necessary. An attempt is made to design castings in which the padding is a permanent part of the casting. There is no particular order of heat treatment and grinding. Welding of castings is accomplished chiefly by means of the electric arc, oxyacetylene welding being used for special purposes only. No preheating is necessary on carbon-steel castings containing less than 0.50 percent carbon if annealing follows welding. All alloy steels are preheated at 100° to 500° C. (212° to 932° F.), depending on the alloy content, size, and shape of the casting. Welding requirements followed were established by the Company for itself to insure acceptable welds. Heat treatment after welding usually consists of heating to above the critical temperature. Only occasionally are the welds given a stress-relieving treatment. Welding rods are used that will produce the weld strengths required in the annealed condition. No destructive testing of welds was undertaken except on very important castings that require welding.

The thickness of the test coupon must be equivalent to that of the average wall section of the casting. Each casting weighing over about 75 pounds must carry a test coupon. The government inspector may use his own judgment as to the number of tests to be made. One casting out of 10 may be selected for removal of the test coupon and tensile testing, or every casting may be selected. The minimum tensile test properties are required regardless of the thickness of the coupon. Company officials thought this requirement to be most undesirable. If hollow-drill tests of the casting are required in heavy castings, permission is granted to reduce ductility 50 percent. Most steel-casting specifications require charpy keyhole notch impact testing.

Percentage of rejections because of scrap castings was only 1 percent. Defects listed in the order of their occurrence are (1) sand and slag inclusions, (2) hot tears, (3) porosity, and (4) shrinkage cavities.

Heat-treating other than annealing consisted of oil and water quenching. All castings containing nickel and aluminum were oil-quenched in accordance with government instructions. Chromium steels were water-quenched (see table 15). Monthly tonnage shipments were as follows:

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Peacetime	Tons per month	Wartime	Tons per month
Wheel centers	700	Armor steel for tanks	700
Small miscellaneous castings ..	500	U-boats and ships	400
Ship castings, press castings, and housings	300	Die blocks	500
Die blocks	500	Forts, West Wall cupolas (when produced)	1,200

Weitmar Plant

The Weitmar plant of Bochum Verein was equipped solely for the production of large steel castings. The plant contained four 60-ton basic open-hearth furnaces fired by coke-oven gas and generator gas. A cold scrap practice was used. Castings up to 240 tons had been produced, which required tapping the four furnaces simultaneously. Furnace practice was similar to that at the Bochum plant.

Molding was carried on in chamotte, and the five types of Forme Masse described previously were used. All large cores were hollowed out and filled with ashes or cinders.

All castings were annealed, and then all the armor castings were quenched in oil or water, according to specifications. The annealing furnaces were fired with coke-oven gas. The quenching tanks held 200 cubic meters of oil or water and were 20 feet square by 25 feet deep. The oil circulated at the rate of 10 cubic meters per minute. Water circulation was a water flow from a 12-inch pipe at 75 pounds pressure. A maximum temperature rise of 50° C. (90° F.) was permitted in the water-quenching tank, whereas an 80° C. (145° F.) rise was permitted in the oil tank. The largest castings quenched in oil were the cupola castings for the West Wall, weighing 200 tons. The largest water-quenched casting was 130 tons of chromium-molybdenum steel. Castings are quenched at 880° C. (1,616° F.). A forge block weighing 63 tons quenched in oil remained in the oil quench for approximately 12 hours before it reached a temperature of approximately 200° C. (392° F.), when it was removed. Temperature of the casting at the time of removal was measured by low melting temperature pencil sticks.

A specialty of the foundry was cast forging die blocks weighing 50 to 100 tons "as cast." These are permitted to cool in the mold, which takes approximately 3 weeks. The temperature of the casting on removal is about 350° C. (662° F.). Rough cleaning takes 10 hours. The temperature of the blocks after cleaning was 200° C. (392° F.), at which they were placed in an annealing furnace and heated to 680° C. (1,256° F.) for relieving casting stresses and to facilitate machining. Castings were furnace-cooled at the rate of 5° C. per hour (9° F.) down to a temperature of 100° C. (212° E.). The risers were then removed by sawing, and the castings were rough-machined. The castings were then heated to 880° to 900° C. (1,616° to 1,652° F.). Sixty-ton castings were heated 30 hours at this temperature. The castings were then quenched in oil or normalized, depending on the design. Sometimes double normalizing was used. After quenching, the castings were tempered at 650° to 680° C. (1,202° to 1,256° F.) for 40 hours.

TABLE 11. - Heat log of 40-ton basic electric furnace, Bochumer Verein

Specification of Cr-Niv cast armor steel:

C	Mn	Si	P	S	Ni	Cr	Mo	V
0.33	0.60	0.35	0.030	0.018	0.80	1.90	0.20	0.08
.38	.80	.50	Max.	Max.	1.10	2.10	Max.	.12

Charge: 9 tons turnings
31 tons steel scrap

Time	Remarks	Analysis C	Mn	P	S	Ni	Cr	Mo
0.00-0.10	Furnace charged							
0.10	Power on							
3.45	Melt down							
	Power off 50 minutes for finishing charging. Total melting time 2.55 hours.							
3.47	1,700 lb. ore	1.02	0.46	0.025	0.033	1.01	1.40	0.13
	650 lb. lime							
4.45	1,100 lb. ore	.69						
5.10	900 lb. ore	.54						
5.35	200 lb. ore	.41						
6.05		.32						
6.30		.23	.35					
6.35-7.700	Removing slag							
	2,200 lb. lime							
	200 lb. fluorspar							
	1,500 lb. spiegeleisen (10% Mn)							
	150 lb. FeSi							
7.30	550 lb. FeCr (65% Cr)							
	180 lb. FeSi (45% Si) dust							
		.29	.40				1.60	
7.45		.31	.48				1.64	
8.00	900 lb. spiegeleisen (10% Mn)	.33	.50		.022		1.61	
8.35	550 lb. FeSi							
	500 lb. FeCr (65% Cr)							
	160 lb. FeV (55% V)							
9.05	Tapped							

Current consumption: 780 kw.-hr./ton.

Final ladle analysis:

C	Mn	Si	P	S	Ni	Cr	Mo	V
0.40	0.62	0.36	0.029	0.013	0.86	2.04	0.12	0.14

TABLE 12. - Heat log of 15-ton basic electric furnace, Bochumer Verein

Specification for gun-turret castings:

C	Mn	Si	P	S	Ni	Cr	Mo	V
0.20	1.00	0.35	0.018	0.018	1.00	1.00	0.20	0.10
.25	1.20	.50	Max.	Max.	Max.	Max.	Max.	.15

Charge: 6 tons turnings
11 tons steel scrap

		Analysis					
Time	Remarks	C	Mn	P/S	Ni	Cr	Mo
0.00	Charging complete						
0.05	Power on						
2.35	Melt down						
	200 lb. ore; 350 lb. lime			P			
2.45		0.18	0.19	0.025	0.28	0.23	0.02
3.15	Removed slag	.10					
	450 lb. ore; 450 lb. lime						
	100 lb. coke						
3.35		.35	.16				
3.50		.19					
4.05		.13					
4.15		.10					
4.20-4.30	Removed slag						
	900 lb. lime						
	100 lb. fluorspar						
	20 lb. coke						
	350 lb. FeMn (75% Mn)						
	150 lb. FeSi (45% Si) dust						
4.55		.15	.61				
5.10	55 lb. Ferro Va (80% V)	.15	.63	S			
5.30	178 lb. FeMn (75% Mn)	.15	.63	.020			
6.05	250 lb. FeSi (45% Si) lump						
6.40	Tapped						

Current consumption: 840 kw.-hr./ton

15 lb. aluminum in ladle

Final ladle analysis:

C	Mn	Si	P	S	Ni	Cr	Mo	V
0.21	1.16	0.35	0.020	0.014	0.21	0.28	0.01	0.12

TABLE 13. - Heat log of 6-ton basic electric furnace, Bochumer Verein

Specification for centrifugal castings:

C	Mn	Si	P	S	Ni	Cr	Mo	V
0.40	1.20	0.20	0.030	0.018	0.50	0.50	0.25	0.10
.45	1.40	.40	Max.	Max.	Max.	1.00	Max.	.15

Charge: 4-1/2 tons turnings
1-1/2 tons steel scrap

Time	Remarks	Analysis					
		C	Mn	P/S	Ni	Cr	Mo
0.00	Charging complete						
0.05	Power on			P			
2.10	Melt down 200 lb. ore; 350 lb. lime	0.39	0.32	0.023	0.54	0.74	0.02
2.40	Removed slag partially; 200 lb. lime	.24					
3.00		.19					
3.15		.17					
3.20-3.30	Removed slag						
	650 lb. lime; 90 lb. fluorspar						
	220 lb. FeMn (50% Mn)						
	65 lb. FeSi powder (45% Si)						
3.50	12 lb. coke	.31	.86	-	-	.49	-
4.05	15 lb. FeV (80% V)	.31	.86				
4.20	170 lb. pig iron (4% C)	.30	.90	.016			
	110 lb. FeMn (Mn 45%)			S			
	22 lb. FeCr (63% Cr)						
4.50	Removed part of slag						
	55 lb. FeSi lump (45% Si)						
5.35	1st tapping 1-1/2 tons with 1 lb. Al						
5.50	2d tapping 1-1/2 tons with 1 lb. Al						
6.00	3d tapping 3 tons (approx.) with 2 lb. Al						

Current consumption: 965 kw.-hr./ton

Final analysis:

C	Mn	Si	P	S	Ni	Cr	Mo	V
0.41	1.45	0.37	0.019	0.011	0.51	0.66	0.03	0.10

TABLE 14. - Heat log of 40-ton basic open-hearth, Bochumer Verein

Specification for armor-steel castings:

Analysis:

C	Mn	Si	P	S	Ni	Cr
0.38	0.60	0.35	0.030	0.030	0.50	2.00
.42	.90	.50	Max.	Max.	Max.	2.30

6.45-7.50	Charging 28 tons steel Scrap (0.038P; S 0.036) 5 tons turnings (1% Cr)			
11.00	3-1/2 tons pig iron 1,100 lb. Spiegel			
11.20	Start boil	0.85 C;	0.50 Mn;	
11.55		.71 C		
12.15	100 lb. line	.57 C;		0.43 Cr.
12.35		.43 C;	.49 Mn;	.48 Cr.
12.50	80 lb. lime			
12.55		.36 C;	.54 Mn.	
13.05	44 lb. aluminum			
13.10	2,400 lb. FeCr (65% Cr, 1.8% C) slag: 9.1% FeO.	.32 C.		
13.30	Tapped; added to ladle 880 lb. FeSi (45% Si) 550 lb. FeMn (35% Mn)			

Final analysis:

C	Mn	Si	P	S	Cr
0.42	0.78	0.40	0.03	0.024	2.23

TABLE 15. - Analysis and heat-treatment of armor cast steel. (Panzerstahlguss), Bochumer Verein, für Gussstahlfabrikation Aktiengesell-shaft

Analysis:

1. Alloy A:
   C 0.32-0.42%
   Mn 0.60-0.90%
   Si 0.20-0.50%
   P 0.03% maximum P plus S not more than
   0.03% maximum 0.05%
   Cr 2.00-2.60%
   Mo 0.20-0.25%
   Ni 0.70-1.20%
   Va 0.10%

2. Alloy B as above, without Mo.

3. Alloy C as above, without Mo and Ni with 0.10% Va.

4. Alloy D as above, without Mo, Ni, and Va.

Heat treatment:

1. Annealing:
   Alloys A to D = anneal to 900°, cool down at open-air temperature to 680°.

2. Hardening:
   Alloys A to C = heating to 880°; quenching in oil.

   Alloy D = heating to 850°; quenching in oil.

3. Tempering:
   Alloy A = heating to 675°; quenching in water.

   Alloy B = heating to 670°; quenching in water.

   Alloy C = heating to 660°; quenching in water.

   Alloy D = heating to 650/655°; quenching in water.

Approximately 2,000 to 3,000 tons of liquid steel was poured monthly to produce 1,200 to 1,500 tons of castings. During the war, this size was reduced; therefore, production during the war years did not increase materially. At the Weitmar Plant, 480 workmen were employed in the foundry.

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PART 3. - FRIEDRICH KRUPP A. G., ESSEN

The Friedrich Krupp Works at Essen contained four steel foundries classified according to the size and type of castings produced. Large miscellaneous steel castings were produced in foundry 1, medium-size castings in foundry 2, small castings in foundry 3, and high-alloy and aircraft castings in foundry 4. Observation of the equipment, methods, and casting production in these foundries was difficult owing to the amount of bomb damage. The large miscellaneous foundry was in the best shape, as the equipment was massive and difficult to damage. The roofs had been smashed in on all the foundries, making visual examination of equipment difficult. The percentage destroyed of each foundry was estimated as follows: Foundry 1, 50 percent; foundry 2, 65 percent; foundry 3, 90 percent; foundry 4, 60 percent.

Most of the destruction occurred in October 1944, so that castings and molds in the open shops were not especially helpful in determining manufacturing practice. The melting shop was destroyed beyond working condition in February 1945. Molten steel was produced in the melting shop and then transported to foundries 1 and 2. Foundries 3 and 4 contained their own melting units. The melting shop produced steel for ingots as well as for the two foundries. When requiring steel, foundries 1 and 2 had to send the melting shop written instructions concerning the type of steel wanted and its temperature and information as to when it would be needed. The melting-shop superintendent and the foundry superintendent were required to work in close harmony.

Steel for castings made in shops 1 and 2 was either basic electric (20-ton furnaces) or basic open-hearth (35-ton furnaces). The steel-making method was similar to that of the Ruhrstahl and Bochumer Verein Companies. Heat logs of typical basic electric and basic open-hearth heats are given in tables 16 and 17.

The company officials interrogated were Dr. Walter, director of the four steel foundries; Dr. Heinrichs, superintendent of foundry 3; and Dr. Klapp, metallurgist.

Foundry 1

Large castings weighing up to 200 tons were produced in this foundry for forging presses, mills, ships, and heavy machinery of all kinds. This foundry was a large jobbing shop, and only one or two castings were required from each pattern at one time. Peacetime production was about 1,500 tons per month of finished castings. This increased to 2,300 tons per month during the war. To produce 1 ton of finished castings, 1.7 tons of liquid steel was required, a yield of approximately 60 percent.

Before pouring of a 100-ton casting can begin, as much as 40 minutes may be required to bring up all the ladles from the various melting units that are needed. Five ladles full of steel were required to pour a 100-ton casting. This was accomplished without interruption of pouring, and the time required was only a few minutes. Arrangements for tapping five furnaces, transporting the steel across the yard, and arranging the ladles in place was a difficult undertaking requiring careful preparation and exact timing.

Most of the castings produced in foundry 1 were carbon steel; however, some low-alloy steels were produced, such as the 2-percent chromium armor steels for 150-ton cupola castings to be placed in the forts on the West Wall.

Molding

It was the general practice to use chamotte molding material for the large castings. The chamotte was graded into various Forms Masse, as discussed under the Bochumer Verein practice. Molding and core making were similar to the Bochumer Verein practice. Molds were dried or baked at 600° to 650° C. (1,112° to 1,202° F.).

Castings of complicated design, which might possibly hot tear in chamotte, were produced in dry-sand molds. Before the war, a natural bonded Belgium sand was used for the dry-sand molds. During the war, sand was obtained near Essen. Two sands were used - (1) Ratingen and (2) Rosenthal. Both were natural bonded sands and were considered good substitutes for the Belgium sand. A blend of the two was used in preparing the sand mixture. The sand was tempered in accordance with practical experience, and water was added until the desired plasticity developed when the sand was gripped in the hand. Moisture content of molding sands was not actually determined, and no method of adding water to mixtures by weighing or metering was used. The dry-sand molds and cores were oven-dried at 250° to 300° C. (482° to 572° F.). Dry-sand cores that required a high degree of collapsibility were made of silica sand, oil, and dextrine and were dried at about 200° C. (428° F.).

The gating and risering, placement of cores and chills, and general details of production of castings in all the foundries were determined by a committee consisting of the foundry superintendent, foundry foreman, core foreman, pattern-making foreman, and foundry technologist. An engineer who acted as a liaison between the customer and the foundry also was available to discuss design problems and other problems with the customer. The Company executives were of the opinion that by this means better castings were produced with a lower than normal percentage of rejections.

Foundry 2

Foundry 2 produced medium-size castings weighing from 100 pounds to 2 or 3 tons. For the most part, the castings produced in this shop in peacetimes were railroad locomotive castings, such as truck castings, driving wheels, cross heads, guides, cylinder covers, bearing housings, etc. Armor castings for tanks and housings for various gun parts were manufactured during wartimes. Approximately 600 tons of liquid steel per month was poured to produce 200 to 300 tons of castings.

The railroad castings were almost entirely made of carbon steel of 52,000 to 75,000 p.s.i. tensile strength. Carbon and alloy steel were used for armament castings.

Approximately 70 percent of the molds were made of chamotte in this foundry; the remaining 30 percent consisted of green and dry sand. The dry sand used was similar to that produced in foundry 1. The green sand consisted of 12 parts Ratingen sand, 18 parts old sand (used Ratingen sand), and 1 part anthracite-coal dust to which about 14 percent water was added. The excessively high moisture content was claimed to be necessary to produce enough green strength in this type of sand. The molds were all skin-dried prior to being filled with steel.

Another type of green sand used was made as follows: Silver sand, 15 parts; yellow sand (Bottrop, Essen), 15 parts; sulfite lye, 1 part; moisture, 4 percent. The Bottrop sand contained enough clay to bond the mixture when one part of sulfite lye was used. This sand was also used as dry sand. Dry-sand molds were sprayed with sulfite lye before drying.

For light and medium-size cores in shop 2, the following mixture was used:

	Parts
Ratingen sand	16
Silver sand	14
Sulfite lye	2
Radiol oil	1

The cores were oven-dried at 250° C. (482° F.).

Railroad trucks of complex design were molded in a special sand mixture to prevent hot tears. These castings were about 8 feet long and 3 feet wide, with a section of 12 to 15 mm. (approximately 3/8 inch). The mixture was as follows: 50 percent chamotte and 50 percent silver sand, to which was added 2 percent oil. The molds were only partly oven-dried.

Foundry 3

Foundry 3 was used primarily for automotive castings and was considered the small castings shop. Approximately 700 to 750 tons per month of liquid steel was poured to produce 450 tons of castings. The foundry also housed the malleable-iron foundry.

Three 20-ton, acid, open-hearth furnaces produced the steel and the white iron for the castings. This foundry was the most mechanized of the four. It contained conveyers for molds and monorails for small pouring ladles. A vertical-type core oven was available, and core blowers provided cores on a production basis. Castings were made for the General Motors Opel automobile, and General Motors assisted the management in setting up the mechanized foundry. It was Dr. Walter's opinion that this foundry had not reached the degree of mechanization to be found in American steel foundries, as the foundrymen, after making the molds, were obliged to pour and shake them out.

For the most part, carbon steel was made in the acid open-hearth furnaces. Some low-alloy steels also were produced, however. The carbon steel was given a normalizing and tempering heat treatment.

The acid open-hearth practice consisted in charging 25 to 50 percent low-phosphorus and sulfur pig iron and the remainder of selected basic steel scrap from the Krupp Works. The furnaces were hand-charged, the operation taking 2 to 3 hours. The melt-down cycle took 4 to 5 hours, because the checker chambers were too small for the furnaces. At melt-down the slag was partly removed, sand was added, and a fracture carbon sample was taken. It was the practice to melt down at 0.40 to 0.60 percent carbon. Iron ore was added at this time at the rate of 200 to 300 pounds per 20-ton charge. The oxidizing period lasted 3 to 3.5 hours, during which time the carbon dropped to 0.20 percent. It was the opinion of company officials that a long oxidizing period was necessary and advisable for the production of quality acid steel.

The boil was stopped by adding all the ferrosilicon and ferromanganese. These alloys were preheated before use to remove hydrogen. A refining period of 1/2 to 3/4 hour followed addition of the ferroalloys, and the heat was tapped at a carbon content of approximately 0.25 percent, silicon 0.35 percent, manganese 0.60 percent, and phosphorus and sulfur 0.035 to 0.040 percent each. No slag control was used. The finishing slag was light green to gray. No aluminum was added to the furnace, ladles, or molds. A heat log of a typical acid open-hearth heat is given in table 18.

Mostly green-sand molding was used in foundry 3. No chamotte was used. The green-sand mixture was as follows:

	Percent
Rosenthal sand	80
Silver sand	20
Dextrine	0.25

Moisture was added until the proper consistency (by the feel test) was reached.

A favorite mixture for both green and dry sand for the shop consisted of 66 percent of the above mixture added to 34 percent of ground-up old-clay graphite crucibles. A mixture of silver sand, oil, and sulfite lye was used with the core blowers.

Foundry 4

Foundry 4 was considered the high-alloy casting shop. In it were produced corrosion- and heat-resistant steels, magnets, 12 to 14 percent manganese steels, and aircraft steel castings. The foundry contained its own melting units of four 2,000-pound induction furnaces and one 2-ton electric-arc furnace. Approximately 800 tons per month of liquid steel was poured to produce 400 tons of finished castings, as follows: 10 to 15 tons aircraft castings, 30 to 40 tons manganese steel, 70 to 80 tons of 18-8, and the remainder thin-walled castings produced in carbon and low-alloy steel.

Sands for foundry 4 were similar to those used in foundry 2; some chamotte molds also were made for the large heat and corrosion casting production.

TABLE 16. - Heat log,, 25-ton basic electric furnace, Friedrich Krupp, Essen

Specification:

C	Si	Mn	P	S	Ni	Cr	V
0.32	0.35	0.60	-	-	0.30	2.1	0.08
.37	.45	.90	-	-	.50	2.5	.13

Charge: 25 tons.

Time	Remarks	Analysis
0.00	Power on	
0.20	600 lb. limestone	
	200 lb. fluorspar	
0.50	300 lb. spiegeleisen (12% Mn)	
1.00	20 lb. charcoal	
1.10	20 lb. charcoal	
1.30	40 lb. pulverized Fe Si (90% Si)	
	40 lb. pulverized Fe Si (75% Si)	
	10 lb. charcoal	
	200 lb. lime	
1.35	40 lb. lump Fe Si (90% Si)	
	16 lb. aluminum	
1.40	1st sample	0.19C; 0.23 Mn; 0.36 Ni
1.55	400 lb. spiegeleisen (12% Mn)	
	360 lb. Fe Mn (45% Mn) 6% C.	
	1,620 lb. Fe Cr (65% Cr, 1% C)	
	200 lb. lime	
2.15	30 lb. pulverized Fe Si (90% Si)	
	30 lb. pulverized Fe Si (75% Si)	
	10 lb. charcoal	
	200 lb. limestone	
2.20	2d sample	0.28 C; 0.69 Mn
2.25	25 lb. Al-Si-Mn alloy	
2.40	20 lb. Fe Si (90% Si) 20 lb. Fe Si (75% Si)	
2.50	20 lb. Fe Si (90% Si) 20 lb. Fe Si (75% Si)	
3.00	20 lb. Fe Si (90% Si) 20 lb. Fe Si (75% Si);	
	200 lb. spiegeleisen	
3.10	20 lb. Fe Si (90% Si); 20 lb. Fe Si (75% Si)	
3.20	20 lb. Fe Si (90% Si) 20 lb. Fe Si (75% Si);	
	200 lb. spiegeleisen	
3.25	10 lb. Fe Si (90% Si), 10 lb. Fe Si 75% Si)	
3.20	Tapped	
	5% melting loss; 250 kw.-hr./ton	

Final analysis:

C	Si	Mn	P	S	Ni	Cr	V
0.32	0.39	0.72	0.013	0.01	0.36	2.42	0.06

TABLE 17. - Heat log, 30-ton basic open-hearth, Friedrich Krupp, Essen

Specification:

C	Si	Mn	P	S	Cr	Ni	Mo	V
0.32	0.25	0.60	0.015	0.015	2.1	0.80	0.20	0.08
.37	.45	.90	Max.	Max.	2.5	-	0.30	.13

Charge:

	Pounds
Pig iron	22,600
Steel scrap	33,400
Spiegel (20% Mn) ...	1,000
Pig iron (7.82% Si).	7,000
Total	64,000
Lime	3,000

		Analysis					
Time	Remarks	C	Mn	P	S	Ni	Mo
0.00	Finished charging. Power on.						
8.00	600 lb. lime; 400 lb. fluorspar						
8.45	Charge melted	0.98	0.44	0.012	0.027	-	-
	400 lb. iron ore						
10.10	600 lb. lime						
	400 lb. ore						
10.40	600 lb. lime	.48	.23	.010	-	1.02	0.08
11.10	150 lb. Fe Mo (70%)	.40	.19				
	100 lb. broken electrodes						
11.45		.47	.22				
12.20		.53	.23			Cr	
12.50	100 lb. iron ore	.39	.22	-	.022	.09	
13.15	2,200 lb. Fe Cr (64.4% Cr, 1% C)						
13.35	220 lb. Fe Mn (58% Mn)						
13.40							
14.00	Furnace shut off						
	800 lb. pulverized alum added to the slag						
14.05	Tapped						
	Added to ladle: Fe Si:275 lb. (47% Si)						
	260 lb. alloy (5% Al, 10% Si, 10% Mn)						
	80 lb. Fe V (82% V), 90 lb. recarburizer.						

End Analysis:

C	Si	Mn	P	S	Cr	Ni	Mo	Va
0.36	0.44	0.67	0.021	0.026	2.29	0.98	0.24	0.13

TABLE 18. - Heat log of 25-ton, acid, open-hearth furnace, Friedrich Krupp, Essen

Specification:

C	Si	Mn	P	S	Cr	Ni
0.20	0.40	0.40	0.040	-	-	-
.25	.50	.55	Max.			

Charge:

	Pounds
Pig iron	14,000
Rolling mill	36,400
Total	50,400

		Analysis					
Time	Remarks	C	Mn	P	S	Cr	Ni
0.00	Power on						
5.30		0.98	0.10	-	-	0.22	-
6.00		.80	.06	0.034	0.034	-	0.16
6.30		.69	-	-	-	-	-
7.00		.57	-	-	-	-	-
7.30	200 lb. iron ore	.54	-	-	-	-	-
8.00	200 lb. iron ore	.45	-	-	-	-	-
8.20	200 lb. iron ore	.39	-	-	-	-	-
8.35		.31	.09	-	-	-	-
8.50		.24	-	-	-	-	-
9.00	400 lb. Fe Si (47% Si) 800 lb. Fe Mn (38% Mn)						
9.15	Tap 16 lb. Al to ladle						

End Analysis:

C	Si	Mn	P	S	Cr	Ni
0.23	0.43	0.44	0.044	0.032	0.26	0.16

Cleaning and Heat-treating Practices

Total rejections for scrap castings in the various shops are as follows: Shop 1, 1.0 to 1.4 percent; shop 2, 1.4 to 1.8 percent; shop 3, 5.0 percent average; and shop 4, 10 percent average. The order of most frequent defects was (1) shrinkage, (2) slag and sand, and (3) hot tears.

The welding was mostly electric, but on thin-walled castings atomic hydrogen welding was used. Some buyers of castings required careful inspection of defective areas prior to welding. Most castings were welded without preheating. Welding rods were of a composition similar to that of the castings. Welding requirements were high for certain railroad castings. Defects must be shown on blue prints, which must be sent to Berlin for review prior to approval for welding.

Bakelite-bonded swing-frame grinding wheels were used and very well liked. Wheels were 50 mm. in diameter and had a surface speed of 4 m. per second (13 feet per second).

Most steels were given a normalizing and tempering treatment. Most armament steels, however, were quenched and tempered. All steels containing nickel were oil-quenched. The chromium steels were water-quenched. Castings weighing up to 150 tons were water-quenched in tanks 5 by 10 meters by 7 meters deep. Fort cupolas of 2.2 percent chromium and 0.28 to 0.30 percent carbon steel were quenched in water at 900° C. (1,652° F.), removed from the water at 200° C. (392° F.), and tempered at 500° to 700° C. (932° to 1,292° F.).

The oil tank was similar in size to the water tank. Both tanks were provided with excellent pump facilities and produce a good circulation of the liquids. The tanks held 140 cubic meters of liquids. The maximum temperature permitted for the quenching oil was 80° C. (176° F.).

In some cases, such as Cr-Mo-V castings of complex design, the castings were first quenched in oil and then reheated above the critical and quenched in water. It was claimed that this was done to retard the possibility of quench cracking.

The maximum capacity of the furnace employed for heating castings prior to quenching was 300 tons. The quenching racks held about 30 to 35 tons of castings, which were quenched at one time. Carbon steel (0.35 to 0.45 percent) of heavy cross section was often water-quenched. Light-sectioned carbon-steel castings of 6 to 7 mm. wall section occasionally were quenched in oil.

Whenever possible, pilot castings were made and sectioned to ascertain the effectiveness of gating and risering methods. Costly castings were radiographed and magnetic-particle tested. The company had X-ray machines and magnaflux equipment.

PART 4. - DEUTSCHE EDELSTAHLWERKE A. G., WERK HOCHFREQUENZ, TIEGELSTAHL, BOCHUM

The Deutsche Edelstahlwerke at Bochum is well known for its production of high-grade centrifugal castings and for its extensive production of high-alloy irons and steels. Company officials interrogated were Dr. Polzguter, inventor of the horizontal casting of tubes technique, and Mr. Haite, the chief engineer. Dr. Polzguter outlined in detail the developments of centrifugal casting of long tubes.

Early Developments - Centrifugal Castings

In 1928, the company first began its experiments with the centrifugal casting of ferrous metals. They successfully produced gray-iron pipe in water-cooled molds. Shortly thereafter they attempted to make steel pipe in water-cooled molds. It was their experience that the low-carbon and low-alloy steels did not have as high fluidity as the heat- and corrosion-resistant steels, so the latter were used for the studies. However, when water-cooled molds were used for steel, poor results were obtained because of the formati of hot tears and cracks. Because of this condition, experiments were then made by using a heavy-walled iron mold instead of the water-cooled mold. Cooling was not fast enough to make castings on the production basis desirable. Some small degree of success was obtained in the static casting of tubes by the use of water-cooled copper molds. These did not lend themselves to the centrifugal casting method because of their high cost, and as copper is soft, the wearing action due to the rolling of the copper mold on steel rolls was high, with the result that mold life was very short.

Further experimentation with water-cooled alloyed steel molds proved that sound tube castings could be made centrifugally with an outside diameter up to 250 mm., 10-mm. wall thickness, and a length of 500 mm. If the 500 mm. length was exceeded, rejections increased considerably. The most serious trouble was that the steel froze to the mold, making it extremely difficult to remove the tube and at the same time shortening the life of the mold materially.

The goal of the company management was to produce tubes 3 meters in length. Several methods were tried to overcome the troubles arising from freezing of steel to the mold. These included (1) increasing the number of revolutions of the mold, (2) controlling the temperature of the cooling water, (3) varying the thickness of the mold walls, and (4) changing the shape of the spout. These experiments were very expensive, as often a mold was damaged so that it could not be used any longer. Experiment proved that by increasing the revolving speed or by increasing the speed of water cooling, hot tears formed. If water cooling was not employed, a heavy mold was required, and the quantity of tubes produced was reduced.

Experiments in lining the mold with chamotte were then carried on. The chamotte lining was rammed with a minimum amount of water to a thickness of approximately 30 mm. Castings produced in such molds were good, but the chamotte stuck to the tubes, and considerable effort was required to remove the casting from the mold and to clean it. There was no special advantage in using the chamotte liner, as it was necessary to wait until the casting had cooled before attempting to remove it, except that there were no hot tears or cracks.

The next development was the use of chamotte liner inserts; but the operation was quite complicated, and the results were not very different from those obtained by the use of rammed chamotte. Dry silica sand was then used as a liner as the next development test. This manipulation proved successful and led to the present practice, which was perfected in 1938.

Present Practice

Washed and dried quartz sand of 0.2 to 0.6 mm. diameter is placed in a pipe, the size of which depends on the inside diameter of the tube. The pipe has a slot along its length, the slot width being about one-fourth the circumference of the pipe. The dry sand is uniformly distributed along the pipe. The mold (of a chromium-molybdenum steel) is rotated at high speed (1,400 r.p.m. for a 9-inch o.d. tube), and the pipe containing the sand is run into the mold. The pipe is tipped in the direction of rotation, and the sand is spilled into the mold uniformly along its length to a depth of 2 to 4 mm. The sand is preheated at 100° C. (212" F.) so that it will be dry. It was found that if the sand layer was much thicker than 4 mm., too great fusion of sand and steel resulted; if thinner than 2 mm., steel would fuse to the mold.

The entire centrifugal casting machine is then rotated vertically through an angle of 5 degrees from the horizontal, the pouring end being elevated. The molten steel is weighed and then poured into the revolving mold. The mold continues to revolve until the casting cools to 1,000° C. (1,832° F.), then the machine is lowered to the horizontal position, and the tube is pulled out of the mold. As the tube is removed, an auxilliary electric motor mounted on the machine slowly rotates the mold to assist in removal of the tube.

The spout does not enter the tube, but stops at its mouth. In some cases an insulated mouthpiece is placed at the entrane of the tube to allow for easy flow of metal. One small to medium-diameter tube can be produced every 15 minutes. Large-diameter tubes of similar cross section can be cast in 20 minutes. Tubes weighing approximately 3 tons require 50 minutes. Wall sections as thick as 450 mm. have been produced centrifugally. The average length of the tubes is 3 meters (approximately 10 feet). Tubes 5 meters (approximately 16-1/2 feet) long have been made, and experimental work on tubes 6 meters (approximately 20 feet) long is contemplated. The minimum wall thickness for 5-meter tubes is 15 to 20 mm.

Mold thickness is the same (40 to 50 mm.) regardless of the wall thickness of the tube, as water cooling is relied upon as the cooling medium. Water entered the jacket surrounding the mold at normal city-water pressure. The temperature of the outflowing water was kept below 60° C. (140° F.)

A 120-horsepower motor was used to revolve the mold. Speeds were calculated on the basis of the number of revolutions the inside diameter of the tube made:

	Inside diameter, mm.	R.p.m.
Large tubes	450	400
Small tubes	100	200

The finish tolerances were 60 to 10 mm. on the outside of the tube and 50 to 20 mm. on the inside. For gun barrels, a 20 mm. allowance was provided on the inside. A maximum of 2,000 tubes can be cast in a single mold if the wall section of the tube is less than 20 mm. A mold life of 500 tubes is considered the minimum. Tubes fail because of heat cracking. Most of these cracks appear at the pouring end of the mold, and if they are small they can be welded. Cracks were not removed by boring out the molds to larger diameters as they were only of sufficient wall when constructed to permit a normal degree of safety. If the tube wall was approximately 100 mm., a maximum of 500 tubes could be expected from the mold.

Approximately 2 percent scrap was obtained if a number of tubes of similar diameter were being produced. Most scrap occurred on the larger sizes. Hot tears caused by mold resistance when the steel ran over the tube ends, and cold sheets resulting from interrupted pouring comprised most of the 2 percent rejections.

The management claimed that there was no solidification of the inner surface of the tube prior to progressive solidification from the outer wall inward, even though the tube had a 450 mm. inside diameter and 100 mm. wall section. No banding segregation caused by irregularities in pouring have been found. The only defect resulting from this condition was hot tears.

Six small horizontal centrifugal casting machines operated by air pressure were available for producing cylinder liners up to 60 pounds. These machines were developed by the Deutsche Edelstahlwerke and were built by Deutsche Eisenwerke.

The machine consists of a frame for transporting the molds to and from the rolls on which the molds rest in a horizontal position. The rolls are turned by a 10-horsepower compressed air-driven motor. The machine is very rugged and simple in construction, without complicated gearing. The molds are constructed of gray iron and are not water-cooled. Details of making the cylinders are given under the section on the Ruhrstahl Annener Works.

Three of the large Deutsche Eisenwerke A. G. Schalker Verein tube machines were installed at the plant. These machines produced approximately 250 tons of high-alloy steel tubes per month in 1944. Production of cylinders amounted to 50 tons per month.

Melting Furnaces

There were four high-frequency induction furnaces of the following capacities in the plant: One 6-ton, 1,600 kv.-a.; one 4-ton, 1,200 kv.-a.; and two 2-ton, 600 kv.-a. All furnaces were acid-lined with silica brick, over which was rammed a chamotte lining. The melting time for these furnaces was 1 to 2 hours with charge to top time of 3 hours. A small amount of sand was used as a slag cover.

Static Castings

All types of heat- and corrosion-resistant castings were produced at this plant (maximum 2 tons pouring weight), amounting to 400 tons per month. Eighty tons of magnet-steel castings (28 percent nickel, 13 percent aluminum) per month were produced from 120 tons of liquid steel. A small quantity of stellite hard-surfacing electrodes also were produced in sand molds.

Castings weighing up to 900 pounds were produced in a green sand of the following mixture:

	Percent
Silver sand (quartz sand)[1]	75
Yellow sand (semi-bonded)[1]	15
Clay sand	4-6
Dextrine	4
Water	4-7

[1] See Ruhrstahl Annener Works report.

No sand-control equipment was used. Sands were prepared according to texture and plasticity determined by feel and observation. The above sand was used for facing. Backing sand was obtained by remulling and adding water. Molds were sprayed with a mixture of water and dextrine. Cores were made from the following mixture:

	Percent
Silver sand	80
Yellow sand	12
Fire clay	2-5
Oil	2-3
Water	5-7

A core wash of silica flour, dextrine, and water was used on the larger cores.

In molding castings, only external chills were used. Gating and risering of castings were not even orthodox. The risers were exceptionally high, and the necks were long and only about one-third the thickness of the riser. Sectioned castings showed cavities in isolated sections. Many small pieces were not fed at all except from gates. Pattern match plates were made in cast iron and weighed approximately 400 pounds for the 36 pieces. Branch gates were used with a 3/8-inch ingate 1/2 inch deep.

The surface appearance of all static castings was below normal. A soft grinding wheel was used for grinding magnets. If pressure is applied, the heat generated cracks the magnets.

Water-quenching tanks were provided for quenching high-alloy castings. Not all castings were quenched, however. All of the heat-treatment equipment was wrecked through bombing.

The high-frequency induction furnaces used for static molding in addition to those already listed are as follows: One 2-ton capacity furnace, one 1-ton capacity furnace, and one 100-pound capacity furnace. The lining was acid, and the melting practice was simply a melting-down practice.

PART 5. - BERGISCHE STAHLINDUSTRIE, REMSCHEID

The Bergische Stahlindustrie at Remscheid is considered by German steel-casting authorities as outstanding in the production of thin-walled castings. Company officials interrogated were Dr. Rosch, technical director, Dr. H. Stein, foundry manager, and R. Hilger, metallurgist.

Production

The company produced ingots, forgings, stampings, and malleable-iron castings besides steel castings. There were two steel foundires - one for miscellaneous casting production, including aircraft castings, and one for automotive and high-alloy castings. Approximately 425 skilled and semi-skilled workmen were employed in the two foundries, 80 percent of whom were Germans working 60 hours per week. Many types of castings were produced; the more important, from the standpoint of quantity, were railroad castings, including driving wheels and brake-drum disks; automotive castings, including axel housings, drive wheels, etc.; tank parts, including drive wheels, front-pieces, wheel housings, and drive housings; oil-drilling and refinery castings; motor housings for U-boats; housings for antiaircraft direction finders for land and submarine installation. Valves and fittings were not manufactured. The miscellaneous shop produced 700 to 800 tons per month and the automotive shop 400 tons per month of finished steel castings.

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Basic Electric Melting Practice

One each of 20-, 10-, and 5-ton Siemens Halske electric furnaces were available. The 5-ton furnace had not been in use for some time. The furnaces were basic-lined with a monolithic lining of dolomite. One course of magnesite brick was laid on the pan and up the sides. Classified sized dolomite mixed with 8 to 12 percent of tar was rammed to a depth of approximately 400 mm. (16 inches). Side walls were rammed behind forms. The average lining life obtained was as follows: Bottom, 500 to 600 heats; side walls, 80 to 100 heats; top, 60 to 80 heats. The top was acid-lined with silica brick laid in the conventional manner.

The 20-ton furnace was stationary, whereas the top was constructed to slide back to permit top charging. The 10-ton furnace was side-charged from a chute. Carbon electrodes were used, but graphite electrodes were preferred. The furnace spouts were lined with chamotte brick. They were well-prepared but were unduly long. No special precautions were taken to construct slag traps, and slag and steel were tapped together.

All ferroalloy additions were heated at 500° C. (932° F.) prior to use to drive off moisture and hydrogen in the alloy. No special care was taken to pre-dry ore or lime, but these were kept in a warm place.

Melting time for the 20-ton furnace was 3-1/2 hours, the oxidation period was 1-1/2 hours, and the refining period 1-3/4 hours. Total time from power on to tap was approximately 6-1/2 hours. Normally, 1,300 to 1,400 tons of liquid steel was produced monthly in the 20-ton furnace. A heat log for the 10-ton furnace is given in table 19. Approximately 850 tons of liquid steel per month was produced in the 10-ton furnace.

No slag control was used except visual examination. It was general practice to use two oxidizing slags and to keep the heat under a white disintegrating slag for 1-1/2 hours. Fine coke dust was used to deoxidize the slag with pulverized calcium-silicon to finish the slag deoxidation when it could be obtained.

When the second oxidizing slag was removed, bar aluminum was added to the open bath in the proportion of approximately 1/2 pound per ton. As soon as the refining slag shaped up to a white slag, all of the ferrosilicon required and the major portion of the manganese necessary was added to the bath. This practice was followed because it was experienced from microscopic examination that higher-quality steel with fewer inclusions was produced. Heats were never tapped under a brown slag. Just prior to tapping, enough FeMn was added to bring the manganese content to the desired percentage, and approximately 0.5 pound of aluminum per ton of steel also was added to the bath. A porosity sample was then poured, which was made by pouring a spoonful of steel into a green-sand mold (2 by 2 by 4 inches) of 5-percent moisture. The steel was continually skimmed, so that pipe formation could be watched. If the metal rose in the mold, the hydrogen content was considered high, and more aluminum was added.

The technical staff believed it could differentiate between porosity caused by hydrogen and nitrogen. If the cavities were silvery and of smooth appearance, the porosity was caused by hydrogen. If the cavities were not shiny or silvery in appearance, nitrogen was responsible for their presence.

The heat was tapped after a minimum of 1,560° C. uncorrected temperature (approximately 3,050° F. corrected) was obtained. The temperature was recorded by sighting an optical pyrometer on a spoonful of steel. Some fluidity studies had been made by the technical staff with both the spiral and the straight-bar test molds. All tests were made in dry-sand molds. Tests were discontinued, as it was observed that the grain size of the sand produced considerable difference in the fluidity results.

During the heat, phosphorus was reduced from 0.6 to 0.25 percent and sulfur from 0.025 to 0.010 percent. The residual aluminum content averaged about 0.008 percent, with a maximum content of 0.02 percent. Both carbon and alloy steels were produced. The favorite alloy steel, which was also used for cast armor, was carbon, 0.20 to 0.40 percent; chromium, 2 percent; molybdenum, 0.20 to 0.30 percent; vanadium, 0.10 to 0.20 percent; manganese, 0.60 to 1.00 percent; and silicon, 0.40 to 0.50 percent.

The 20-ton furnace averaged 750 to 800 kw.-hr. per ton, and the 10-ton furnace averaged 800 to 850 kw.-hr. per ton.

The ladles were lined with high-grade (high Al_2O_3 content) chamotte brick. Ground-silica brick and ground chamotte were used as the bond material between the brick.

Acid Electric Practice

Bergische Stahlindustrie was one of the two steel foundries in Germany using the acid electric process. Three 2-ton Heroult furnaces (2,400 Kv.-a.) were overloaded to melt 3 and 4 tons. The furnaces were thinly lined, and stand-by shells were provided for relining while the furnaces were in operation. The furnaces were charged with basic electric furnace steel in the form of foundry returns. The acid steel was produced in the foundry manufacturing automotive castings. The reason given for the use of the acid steel was that the castings were not required to equal the high quality of those produced in the miscellaneous-casting shop. Also, the greater fluidity of acid steel was desired for the hand shanking of castings. A high degree of fluidity was needed, as each molder was required to pour the castings he produced.

Each furnace was able to produce four heats in 20 hours. Melting time required 2 to 2-1/2 hours, and the oxidizing period plus the refining period equaled 1-1/2 hours. The furnace was constructed with a thin refractory lining so that it could hold a large quantity of steel. Only one course of silica brick was used on the sides and three courses on the bottom. Sand and water glass were mixed together and rammed to a depth of 150 to 200 mm. to complete the building of the bottom. The life of the linings was as follows: Bottom, 60 heats maximum; side walls, 60 heats maximum; top, 150 to 180 heats.

Melting practice consisted of adding iron ore to the charge and then making another addition of ore at melt-down time. A total of 550 pounds of iron ore normally was added to a 4-ton heat (approximately 7 percent of the charge). The carbon content at melt-down was normally 0.30 to 0.40 percent. It was claimed that following the boil the carbon content was 0.15 to 0.20 percent and that the heats finished 0.20 to 0.30 percent carbon. The manganese content after the boil was normally 0.10 to 0.15 percent, whereas the silicon content was 0.02 percent at the same time. Carbon briquettes were added to the charge if it was believed that the carbon content would be lower than 0.30 percent at melt-down. The FeO content of the oxidizing slag was 25 to 40 percent.

Spiegeleisen was used to slow the boil. It was the practice to boil the heat for about 1 hour. A partial slag-off was made at the end of the boil to lower the FeO content. Sand was then added to form the second slag, followed by a limestone addition to thin the slag if such were necessary. Limestone was used in preference to fluorspar because it was claimed that fusion of the slag proceeded at a faster rate. It was the practice to dip the electrodes into the bath whenever it was necessary to recarburize the heat.

Slag control was not used, except for examination of the fracture collar of the slag. A light-green finish slag was the aim. During the refining period, a silicon reduction of approximately 0.13 percent was obtained. Ferrosilicon was added 20 minutes before tapping, and ferromanganese was added 5 minutes before tapping. The FeO content of the slag prior to tapping was thought to be 8 to 12 percent. Aluminum additions were made to the bottom of the ladle at the rate of 0.9 to 1.1 pound per ton, and the steel was tapped upon it. No arrangements were made for holding back the slag. The ladle slag was thought to be as follows: 2 percent FeO, 9 percent MnO, 60 percent SiO_2, and 10 to 15 percent CaO. The tapping temperature was 1,570° C. uncorrected as a minimum (3,075° F. corrected). A typical acid electric heat log is given in table 20.

Aluminum was always added to the hand shanks at the rate of about 0.4 pound per ton. Chromium recovery could be expected at a rate of about 65 percent. It was also the practice to save the high-chromium slags and use those on low-chromium heats.

In the use of ferrosilicon, it was the normal practice in Germany to use the 75-percent silicon type because of the lower percentage of H_3P present. It was believed by the technical staff of this company that the high aluminum content of the 5-percent silicon type was responsible for the presence of H_3P.

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TABLE 19. - Basic electric heat log, 10-ton furnace, Deutsche Edelstahlwerke, Remscheid

Final analysis: 0.27% C; 0.68% Mn; 0.46% Si; 0.03% P; 0.009% S.

Time	Sample	Remarks	Analysis
0.00		Power on; weight of charge 19,000 lb.	
2.00		Melt down; 200 lb. iron ore, 80 lb. fluorspar; 300 lb. lime; 80 lb. limestone.	
2.40	1st		0.56% C
2.50		200 lb. iron ore; 80 lb. limestone.	
3.20		1st oxidizing slag removed.	
3.25		450 lb. iron ore; 120 lb. fluorspar; 600 lb. lime.	
3.50		2d oxidizing slag removed.	
3.55	3d		0.18% C; 0.14% Mn
3.58		0.5 lb./ton aluminum, 200 lb. lime.	
4.00		260 lb. spiegel; 45 lb. carbon briquets; 120 lb. fluorspar; 300 lb. lime.	
4.20	3d		0.20% C; 0.25% Mn
4.25		Porosity sample: Rising, 75 lb. Fe Si (75% Si).	
4.40		Porosity sample: Shrinking, 200 lb. pig iron.	
4.50		Porosity sample: Slight rise, 20 lb. Fe Si (75% Si), 8 lb. total Al added. Porosity sample: Shrinking.	
5.00		Tapped - kw.-hr./ton: 880.	

TABLE 20. - Acid electric heat log, 4-ton furnace, Deutsche Edelstahlwerke, Remscheid

Final analysis: 0.31% C; 0.58% Mn; 0.50% Si; 0.048% P; 0.04% S.

Time	Remarks
0.00	Power on; weight of charge 9,000 lb.
1.40	Melt down.
2.25	1st test: 0.25% C.
3.10	2d test: .18% C.
3.15	90 lb. spiegel; 20 lb. Fe Si (45% Si); 60 lb. sand.
3.40	3d test: 0.29% C; 0.30% Mn; 10 lb. Fe Si (45% Si).
4.00	4th test: .25% C; 290 lb. spiegel.
4.10	5th test: .33% C.
4.20	Tapped; 0.2 lb./ton Al to ladle. Kw.-hr./ton: 820.

Induction-Furnace Melting

Three high-frequency induction furnaces were employed for the productic of high-alloy castings, as follows: One 800-pound capacity and two 2,000-pound capacity furnaces. Approximately 120 tons of liquid high-alloy steels were produced monthly, which yielded 60 to 80 tons of finished castings. The furnaces were acid-lined, but no slag was employed. The melting method employed was a straight melt-down practice. Castings produced were mostly pump parts for the chemical industry. Return bends of 5-percent chromium and 0.5 percent molybdenum also were produced.

Molding Practice

Castings weighing up to 2,000 pounds were molded in green and dry sands. Castings weighing over 2,000 pounds were molded in chamotte containing 30 to 50 mm. (approximately 1 to 2 inches) as facing sand. The green and dry sands were made similarly, the only difference being that all the alloy steels were made in oven-dried sands, whereas the carbon steels were produced in green sands. These sands were made by mixing quartz (silver) sand and clay. Two types of clay were used - (1) Westerwalde and (2) Rhine area. The Rhine area clay had about twice the bonding power of the Westerwalde clay. A synthetic bentonite produced by Huttenes, Düsseldorf, was used in conjunction with the dextrine sand. The green and dry sand mixes used were as follows:

	Type A	Type B	Type C
Silver sand, parts	18	18	18
Rhine area clay, parts ..	-	3	-
Westewalde clay, parts..	6	-	-
Dextrine, parts	1	1	1
Bentonite, parts	-	-	1.5
Water, percent	5	5	5

The permeability of the sand was low. Molding sands prepared for castings weighing near the dividing line between green sand and chamotte were increased in clay content. Small cores were produced from types A and B, but large cores were made of an oil sand as follows:

	Parts
Silver sand	16
Clay	1-2
Radiol oil	1-1-1/3

Core wash was not used, and cores were dried at 180° C. (356° F.). The chamotte sand was prepared by mixing 18 parts chamotte with 3 to 6 parts clay. Chamotte molds were dired at 400° C. (752° F.).

All green, dry, dextrine, and chamotte molds were shaken out in one place. The mixture was then mulled, water was added, and the mixture was used as backing sands for all molds, either chamotte or green-sand.

Molds for high-alloy castings consisted of dextrine to which 2.5 to 3 percent sulfite lye (lignin) and 3 percent water were added.

The gating and heading requirements of the castings was worked out in the pattern shop by a responsible engineer. Rules applied were chiefly those adopted as the result of past experience. Pilot castings were studied only if the quantity to be made would warrant the expense and time required.

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Aircraft castings were radiographed in accordance with government specifications. Castings for U-boats weighing 1,000 and 1,500 pounds were given 100-percent magnetic-particle inspection. Test bars were placed according to customer requirements. An attempt was made to follow controlled directional solidification requirements, and gating into risers was practiced whenever possible. No internal chills were used on castings requiring high strength. External chills were used liberally; for example, 60 chills were used on a tank-armor casting that gave a 35-percent yield. Some castings were produced (a railroad brake-drum disk) with only a 30-percent yield.

The thinnest casting produced, for a truck front gear housing, had a 3/16-inch wall and was 12 inches long. Most castings, however, had a wall selection greater than half an inch.

Most risers were sawed from the castings on large disk saws. Company officials realized that this practice was more expensive than burning off the risers, but it was preferred because of the clean and neat cut. As the cut-off disk could not be brought close to the casting, in many cases considerable grinding was necessary. Company officials were not particularly interested in the technology of grinding or cleaning. Surface appearance of the castings was not exceptional. The larger castings produced in chamotte had the best surfaces. The surface on the high-alloy castings was very rough, necessitating considerable cleaning and much grinding.

Approximately 2 to 3 percent of the castings produced were scrapped. Individual castings, such as the drive-wheel castings for Tiger tanks, showed scrap losses as great as 20 percent. Most scrap losses were due to hot tears and quenching cracks. As the castings contained such a large proportion of risers, only few rejections resulted from shrinkage. Approximately 40 percent yield was all that was obtained for the entire plant production. Twenty percent maximum rejections were obtained for aircraft castings. These rejections were due chiefly to quenching cracks and being outside the tolerances specified.

Normally, electric-arc welding was used for repairs, but on thin-walled castings atomic hydrogen welding was preferred. Carbon steel and low-strength steels were welded with carbon and low-alloy welding rods. Preheating was not used, but castings were heated above the critical after welding. Highly stressed castings, such as the chromium-molybdenum armor castings, were welded with austenitic rods. These castings were welded without preheating and were not stress-relieved.

Castings were annealed in 15- to 20-ton furnaces. The annealing treatment preceded a quenching treatment if this was required. Only a small percentage of the product was normalized or water-quenched, whereas approximately 360 tons of finished castings per month were oil-quenched. The oil-circulation requirement was that the oil temperature should not exceed 120° C. (248° F.). Normally, the oil temperature was 60° to 80° C. (140° to 176° F.). The heating furnaces for quenching handled loads up to 18 tons and were gas-fired. A batch of 2 to 3 tons of castings was quenched at one time. The production of aircraft castings resulted in a higher percentage of quenched castings than is normal. The properties of the Cr-Mo-V steel used for armor are as follows:

Chemical analysis	Percent	Heat treatment
C	0.38	Normalize 900° C. (1,652° F.).
Mn	.66	Oil-quench 850° C. (1,562° F.).
Si	.41	Temper 550° C. (1,022° F.).
P	.021	Mechanical properties.
S	.009	Tensils psi, 85,000-92,000.
Cr	2.23	Yield psi, 71,000 min.
Mo	.26	Elongation %, 25 min.
V	.11	Reduction of area %, 45 min.

PART 6. - DEUTSCHE EISENWERKE, MÜLHEIM

The Deutsche Eisenwerke in Mülheim is a large steel works consisting of blast furnaces, coke ovens, ingot production, rolling mills, forge plant, cast-iron foundry, and steel foundries and employing 8,000 workmen. There were two steel foundries - a small casting foundry producing castings up to approximately 300 pounds and a large casting foundry making castings of 150 pounds to several tons. Total production of the two foundries in 1944 was approximately 2,500 tons per month. The small foundry was 95 percent in working condition, whereas the large foundry was about 80 percent ready for operation. Company officials interrogated were P. Bergmann, superintendent of the small castings foundry, and R. Nikolay, superintendent of the large castings foundry.

Small Castings Foundry

Steel for castings produced in this foundry was made by both converter practice and electric furnaces. Approximately 70 percent of the molten steel produced, or 1,050 tons per month, was made by the converter practice.

Converter Practice

Four cupolas with an inside diameter of 60 cm. (24 inches) were available for producing molten iron for the converters. These cupolas produced iron at the rate of 6 tons per hour. Only two were operated at a time while the remaining two were being prepared for operation. The two furnaces in operation ran 16 hours a day for three days before the bottoms were dropped. They were banked at night. The charge consisted of 70 to 80 percent steel scrap, approximately 5 percent silvery pig iron (low-silicon pig), and the remainder was hematite pig iron. The content of cupola iron at the spout was 2.1 to 2.5 percent carbon, 1.5 to 1.7 percent silicon, 0.3 to 0.4 percent manganese, 0.07 to 0.08 percent phosphorus, and 0.1 to 0.16 percent sulfur.

The cupola iron was desulfurized with powdered, fused, soda ash at the rate of 0.01 percent of the weight of the charge. The sulfur content was reduced to 0.06 to 0.08 percent. For certain castings, where the maximum sulfur content is not specified, desulfurization is not required. The cupola melting loss was calculated as approximately 10 to 12 percent.

Four side-blown, acid-lined converters were available for making steel. The capacity of these furnaces was 1.7 to 2 tons. Two blastmen operated the four converters. The converters were lined similarly to those described at Gusstahlwerke Risch (see Part &). The lining life was 80 to 100 heats. Approximately 12 converter shells were available for relining, so that there were always completely lined shells ready for use. Blowing time was 15 to 17 minutes, with finishing carbon content approximately 0.10 percent. Ferromanganese and ferrosilicon were added to the hot ladle and permitted to heat to about 800° C. (1,472° F.) prior to tapping the converter heat. Bar aluminum was plunged into the ladle at the ratio of 4 pounds per ton. Steel was top- and bottom-poured from acid-lined ladles. Average analyses of carbon-steel castings produced from converter steel were as follows:

C	Si	Mn	P	S
0.25	0.29	0.68	0.075	0.108
.35	.33	.60	.081	.099

Electric-furnace Practice

A 3-ton and an 8-ton furnace were available. The 8-ton furnace has not been in use for the last 2 years, as the transformer equipment has been damaged. The furnace was operated according to basic practice. Wall life was approximately 100 heats, and the life of the silica roof was about 60 heats. The 3-ton furnace was charged upwards to 4-1/2 tons. The lining life was 70 to 80 heats, whereas the roof life was 50 to 60 heats. A production of 450 tons per month was obtained from this furnace. All low-manganese and all 12- to 14-percent manganese steel, approximately one-third of the electric-furnace production, was made in the electric furnace. The furnaces were lined in the usual manner employed in Germany of ramming a mixture of dolomite and tar on top of the magnesite brick. All electric-furnace steel was poured from bottom-pour chamotte-lined ladles, except the 12- to 14-percent manganese steel, which was top-poured. A furnace log for the 3-ton electric furnace is given in table 21.

Molding and Casting Production

Molds were both hand-rammed and machine-molded. A number of squeeze machines and jolt, squueze, roll-over machines were available; however, castings were removed from these machines by large overhead cranes. Sand was delivered to the machines in buckets by overhead cranes. Lack of mold-moving facilities, such as roller conveyors, etc., was responsible for low production from the machines. A review of gating and feeding methods revealed that for the most part the risers were too large, both in height and diameter, for the castings being fed. This accounts for the fact that only 50 percent yield was obtained for castings that in general were not of complicated design. Some castings, which were not of high quality, were produced with virtually no risers. Whenever possible, the casting was gated down risers. All gates and riser patterns were loose-monted, which led to the misplacement of risers in some cases. The technique of the application of gates and risers and the lining-up of molding requirements appeared to be rather poor.

The sand for this foundry was called a green sand, though the molds were permitted to air-dry before pouring. The facing-sand mixture, by weight, for the green-sand molds was as follows:

	Percent
Silver (quartz) sand	32.0
Ratingen (natural-bonded) sand	32.0
Old sand (used facing sand)	32.0
Core binder (cereal)	2.5
Radiol (core oil)	1.5
	100.0
Moisture	7-8

The sand mixture was quite dense and air-dried to a very hard surface. No wash was used. The casting surface was rather poor, and the sand did not peel easily. Daily sand testing was carried on, and tests were made in the Georg Fisher Co. testing equipment. Castings were not cleaned prior to annealing. A heavy oxide scale was formed during annealing, which aided in removing the sand from the castings. All castings were given an annealing heat treatment. The casting surface was very poor, probably because nearly all castings required rough machining at the plant.

Miscellaneous castings were produced, including castings for tanks, gear housings, bearing housings, and truck castings. Brake drums for airplanes made of 0.80- to 0.85-percent carbon steel were water-quenched after annealing. This casting was an ideal one for centrifugal casting but was produced statically at this plant.

Large Casting Foundry

Melting equipment in the large casting foundry consisted of two 15-ton, acid, open-hearth furnaces, one 20-ton, basic, open-hearth, one 10-ton, basic, electric Stein Roubai furnace, and one 8-ton, basic, electric Siemens furnace. The basic open-hearth furnace was used for melting plain carbon steel, whereas the electric furnaces produce both carbon and low-alloy steels. Prior to the war, three open-hearth heats were produced per day, which was equivalent to about 1,300 tons per month. During the last few years of the war only two heats were made per day, or approximately 700 tons per month. This reduction was due to the fact that the electric furnaces were installed during the war years. The electric furnaces produced 3 to 4 heats per day, or 1,600 tons per month. Of the total basic open-hearth and electric furnace production, only 1,000 tons of molten steel was used for castings in this shop. This figure did not include the 600 tons of liquid steel produced monthly by the acid furnaces. The acid steel was used exclusively for mine-car wheels and for narrow-gage dump-car wheels. Acid open-hearth steel was used for these castings because they were not high-quality castings with limits on phosphorus or sulfur contents; also, it was desired to top-pour these castings from small ladles. Approximately 66 percent yield was obtained on these castings, or about 400 tons of finished wheels per month. Only carbon steel was produced in the acid open-hearth furnaces.

The production of basic furnaces (one open-hearth and two electric) was 50 percent for ordnance work and 50 percent for machine parts, which included rolling-mill machinery, mining castings, gears, hydraulic presses, blast-furnace parts, and railroad castings. The steel-making practices of the basic furnaces were similar to those found in other German foundries. A typical heat log of the 10-ton electric furnace is insluded in table 22. Some 1.0 to 1.5 percent chromium armor castings for tanks were produced. These were oil-quenched, but during the latter part of 1944 they were water-quenched, owing to the lack of oil.

All the large castings - the majority of the castings - were cast in chamotte molds. Casting surfaces were improved as compared with castings produced in the small foundry. Heading and gating were orthodox.

One interesting development was the production of track guide wheels for tanks. These wheels weighed 170 pounds with gates and risers and 140 pounds with gates and risers removed, or a yield of 82 percent. The steel was poured in a permanent cast-iron circular mold produced in three parts and assembled by locking the metal molds one on top of the other. An oil-sand core was set in the center of the assembled mold, a green-sand core, including the risers, was rammed up and placed over the metal mold. Excellent directional solidification was obtained toward the center of the wheel. The cast-iron molds were 5 inches thick. The mold was poured through the risers. Monthly production was 2,000 wheels per month, and it was stated that production could have been more than doubled if the demand required it.

One portion of the foundry was devoted to the production of 150-mm. projectiles. Approximately 900 tons per month of converter steel was used to produce 800 tons per month of projectiles. The steel for these projectiles was made in separate unit of two cupolas and one side-blown 2-ton converter. The projectiles were made of carbon steel of the following analysis: Carbon, 0.35 to 0.45 percent; manganese, 0.70 percent; phosphorus, 0.10 percent maximum; sulfur, 0.13 percent maximum. The projectiles were given on an annealing treatment. The nose of the projectile was not cast as a part of the shell.

The projectiles were poured into cast-iron molds. The mold was so constructed that four projectiles were cast in the same mold. An oil-sand core, thickly washed, was inserted at the nose portion of the projectile to stand upright. The base of the projectile was uppermost in the mold and was stopped off at the proper height by a cover core. The cover core contained 8 pencil gates of 1/2-inch diameter equally spaced around the circumference of the projectile. Steel was poured into a centrally placed runner cup, which distributed steel to the four molds. The projectile section was approximately 1-3/8 inches. Risers were not used to feed the casting, and the inner surface of the projectile was not machined.

Rejections of faulty castings were as follows:

	Percent
Small castings shop	7-9
Large castings shop	3-4

Most defects were caused by shrinkage, hot tears, and misruns.

TABLE 21. - Heat log for 3-ton basic electric furnace, Deutsche Eisenwerke, Mülheim

Specification:

C	Mn	Si	P	S	Tensile:
0.42	0.55	0.35	0.030	0.020	85,000
.46	.60		Max.	Max.	p.s.i.

Charge:

	Pounds
Steel scrap	3,000
Gates and risers	4,000
Turnings	2,000
	9,000

		Analysis		
Time	Remarks	C	Mn	P
0.00	Power on			
2.45	1st sample	0.30		
3.10	Boil			
3.30	2d sample	.12	0.18	
3.40	Slag removed; recarburized			
4.15	3d sample	.36		
	150 lb. spiegeleisen (18% Mn)			
	10 lb. FeMn (70 % Mn)			
5.00	4th sample	.42	.66	0.026
	60 lb. ferrosilicon (29% Si)			
5.45	Tapped approximately, 8,600 lb.			
	25 lb. CaSi in ladle			

End analysis:

C	Mn	Si	P	S
0.42	0.68	0.27	0.028	0.019

Current consumption: 790 kw.-hr./ton.

TABLE 22. - Heat log of 8-ton basic electric furnace, large foundry, Deutsche Eisenwerke, Mulheim

Specification:

C	Mn	Si	P	S	Tensile strength
0.24	0.50	0.45	0.03	0.02	65,000
.28	.60	.55	Max.	Max.	p.s.i.

Charge:

	Pounds
Steel scrap	3,200
Gates and risers	11,600
Steel scrap (1.2 Mn)	4,400
Turnings	6,800
	26,000

Time	Remarks	Analysis C	Mn	P	S
0.00	Power on				
3.15	1st test	0.34		0.028	0.040
3.55	Boil				
4.15	2d test	.19	0.10	.02	.045
4.20	Slag removed				
4.30	450 lb. spiegel (18% Mn)				
5.00	3d test, 300 lb. FeSi (45% Si)	.24	.40	-	.040
5.30	4th test, 35 lb. FeMn (70% Mn)	.24	-	-	.035
6.00	Tapped, 6-1/2 lb. aluminum in ladle Tapped approximately 24,600 lb.				

Current consumption: 810 kw.-hr./ton

End analysis:

C	Mn	Si	P	S
0.24	0.67	0.40	0.018	0.018

PART 7. - SMALL STEEL FOUNDRIES OF THE RUHR

Gusstahlwerk Risch, Bergisch Gladbach

Gusstahlwerk Risch is a medium-size foundry producing approximately 500 tons per month of miscellaneous steel castings and employing 180 men. The company operated an up-to-date pattern shop and an extensive machine shop for the rough-machining of castings. The plant stopped operating on March 7, 1945, when United States troops moved into the area. The plant was not damaged. The individuals interrogated were Mr. Risch, the manager-owner, and Mr. Vorhauer, the foundry superintendent.

During the war approximately 60 percent of production was ordnance castings, such as gun mounts, machine-gun housings, tank drive wheels, and other miscellaneous tank parts. The remaining 40 percent consisted of mine-equipment castings, locomotive castings, gears, and miscellaneous machinery castings.

Basic Electric Practice

The company operated a 2-ton basic electric furnace, which was used to make carbon and low-manganese steel. It was lined with magnesite brick on the bottom and side walls, over which was rammed dolomite and tar to form a monolithic lining. Maximum refractory life for the side walls was 100 heats; the average life was 86 heats. Maximum roof life was 86 heats; the average was 70 heats. The roof was lined with silica brick. Voltage taps of 155 and 80 were available and used. The electrodes were graphite, and production records showed 1 ton of steel melted per 15 pounds of electrodes consumed. The kilowatt hours ranged from 800 to 990, with about 880 as average. The practice followed was the typical basic electric-arc practice used throughout Germany and previously described. The only difference was that the ferro-alloys were not heated prior to their addition to the bath; also, aluminum was added to the ladle in the ratio of 0.5 pound per ton.

Converter Practice

One 2-ton acid-lined converter produced approximately 80 percent of all the steel made for castings. Two cupolas were available to provide the converter with molten iron. The cupola charge consisted of:

	Kg.	Percent
Hematite pig iron	110	27.5
Blast-furnace Si pig	15	3.7
Spiegeleisen (15% Mn)	20	5.0
Steel scrap stampings	120	30.0
Cast steel (foundry returns)	133	33.8
	400	(880 lb.)

The hematite pig-iron composition is as follows: Silicon, 3.2 percent; carbon, 3.8 percent; manganese, 0.80 percent; phosphorus, 0.08 percent; and sulfur, 0.04 percent. The analysis of the blast-furnace silicon pig iron is: Silicon, 10.0 percent; carbon, 3.2 percent; manganese, 1.5 percent; phosphorus, 0.06 percent, and sulfur, 0.04 percent. The coke content of the cupola charge was 14 percent and the limestone content was 7.5 percent.

The cupola loss was 13 percent in metal and 10 percent in silicon. A sulfur pick-up owing to the sulfur content of the coke and scrap took place, so that the cupola iron at the spout had approximately the following composition: Carbon, 2.7 to 3.0 percent; silicon, 1.3 to 1.6 percent; manganese, 0.50 to 0.60 percent; sulfur, 0.12 to 0.14 percent; and phosphorus, 0.06 to 0.07 percent. For preliminary heat generation the management preferred about 0.55 percent manganese, and by experience it was found that silicon in the ranges given above was the most satisfactory. A silicon content of about 1.6 percent is used for the first few charges after starting with a cold converter. After three heats are blown, the silicon is reduced to 1.2 to 1.5 percent. Sulfur and phosphorus are kept as low as possible.

Pulverized soda ash is used for desulfurizing. Approximately 15 pounds soda ash are used per ton of cupola iron (0.7 percent). The soda ash plus

2 pounds per ton of briquet coal are added to the bottom of the ladle, and the cupola iron, the temperature of which is about 1,300° C. (2,372° F.), is tapped on top of them. The sulfur is reduced from 0.12 to 0.14 percent to about 0.05 percent. The sulfur-containing slag is removed, and the cupola iron is weighed. It is now ready for charging into the converter.

The converter is lined by placing a course of chamotte brick next to the shell, as shown in figure 3. A layer of quartz refractory bonded sand (Eisenberger Klebsand) is rammed against the bricks to a depth of about 150 mm. on the side walls and to a flat base on the bottom, shown in figure 3. Analysis of the Eisenberger Klebsand is as follows: 91.67 percent SiO_2, 0.41 percent TiO_2, 0.58 percent FeO, 6.71 percent clay, 0.14 percent MgO, and 0.49 percent alkalies.

The bottom of the converter is constructed of silica brick, and the sides are sahped by means of large specially shaped silica brick. The removal top of the converter is rammed with the refractory sand, and the chamotte brick is used as a shell lining and spout cover.

Large bricks are used in order to keep the number of joints to a minimum. These bricks are 10 cm. (4 inches) thick, which enables full use of them before relining. An average of 85 to 90 heats per lining was obtained, with a maximum of 103 heats for the type of lining described. The average life of converter lining in German foundries using the converter, according to company officials, is about 50 heats. It was believed by these officials, that the type of lining described will have nearly double the normal lining life. The moisture of the rammed sand must be kept as low as possible. Normally, not to exceed 5 percent moisture is used. The tuyere walls are also lined with silica brick. One lining requires 28 specially shaped radial bricks and 184 standard silica bricks. Silica mortar with the addition of a small percentage of clay is used. Three days are required to dry a lining. The converter is then filled with coke, and air is blown through for 1 hour. Preheating of the converter is very important to prevent excessive melting losses.

The weighed iron is added to the converter, which is rotated about 5 degrees until the top of the bath reaches the tuyeres, at which time the air blast is started. Blowing a charge requires 15 to 25 minutes, depending on (1) the latent heat of the converter, (2) the temperature of the cupola iron, (3) analysis of the charge, (4) weight of the charge, and (5) blast pressure.

High blast pressure shortens the heating time, but if the blast is too high the melting losses are high. It was the experience of the company that the blast pressure for a 2-ton converter should be (2- to 3-inch water column) 3 to 4.5 pounds per square inch. Metal loss in the 2-ton converter was 7 to 8 percent. There was also a lining loss. This condition was corrected by increasing the weight of the charge by about 200 to 400 pounds per day. Approximately 25 heats can be made in 12 hours.

The blow is stopped when the carbon content of the bath is about 0.06 percent. The steel is recarbonized by the addition of Spiegel and ferromanganese to the converter. These alloys are added after they have been furnace-heated to about 800° C. (1,472° F.) to avoid excessive loss of manganese. As is shown by table 23, manganese losses of 20 to 25 percent can be avoided by preheating the ferromanganese. Ferrosilicon is placed on the bottom of the ladle. The heat is tapped at approximately 1,700° C. (3,092° F.). Additions of 1/4 pound aluminum per ton of steel are added to the ladle. Acid-lined ladles were used for both electric and converter steel. Electric and converter steel were similar in mechanical properties except for impact values, and in this case the impact value for converter steel was about half that for electric steel. Presumably this is due to the higher phosphorus and sulfur contents of converter steel.

Molding

An approximate 50 percent yield is obtained in the production of castings at this foundry. Special consideration is given to gating and feeding castings, which is planned by the owner-manager and the foundry superintendent. For the most part, the technique appeared good, except, like all German practice, that the risers seemed too high for their cross-sectional area. Slight short necks were used.

TABLE 23. - High manganese yield in converter practice through preheating of Fe-Mn, Gusstahlwerke Risch

Without preheating FeMn

Converter charge: 3,200 lb. steel
Added to ladle: 128 lb. FeMn (46% Mn)
12 lb. FeSi (75% Si)
1.2 lb. aluminum

	Percent
Calculated Mn	1.38
By analysis	1.00
	0.83
Loss	45

With preheating FeMn

Converter charge: 3,200 lb. steel
Added to converter: 60 lb. Spiegel (20% Mn)

Added to ladle:
Preheated 1,200°-1,300° F: (64 lb. FeMn (46% Mn)
(12 lb. FeSi (75% Si)
1.2 lb. aluminum

	Percent
Calculated Mn	1.293
By analysis	1.093
	0.200
Loss	16

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Green-sand practice constituted 60 percent of all the molding. Castings up to 800 pounds and 50 mm. (2 inches) wall thickness were produced in green sand. Such castings as locomotive driving wheels were produced in green sand. Chamotte-sand molding, with its various grades of Form Masse, was used for 30 percent of the production. The remaining 10 percent was made in cement sand. The green sand was mixed as follows:

	Percent
Rosenthaler sand (natural-bonded)	89
Silver sand	10
Stabil (special clay)	1

The sand was mixed to a moisture content of 4 to 5 percent. The sand was permitted to air-dry prior to pouring. The cement sand was used only for thin-walled castings up to about 1 inch.

Care was given to the remulling and tempering of backing sand, and a small sand-distribution system was provided.

Two core-blowing machines of Vogel-Schemmann construction were available for blowing of core-sand small molds. The air pressure for all of the Vogel-Schemmann machines is 90 pounds per square inch. The large core-blowing machine weighed about 2 tons, and cores weighing as much as 33 pounds could be made by the machine. The average size of cores made on the large core blower was 20 to 25 pounds. One such core could be made every 8 minutes, including laying core wires, etc. The sand capacity of the machine was 60 gallons. An electric motor kept the sand in motion in the feed chamber. Cores 20 by 8 by 6 inches were easily blown by this machine. The shop contained 50 molding machines of various types. Conveyers were provided to move the molds away from the machines. Only overhead cranes were used.

The cleaning room was quite modern, with 5 wheel abrators housed in a separate room. A room blast built to handle the cleaning of railroad driving wheels also was available. Heat-treating consisted of annealing. Cooling in the furnace was speeded by opening the furnace door slightly and blowing in air through ports on the top of the furnace.

Rejections were approximately 2.2 percent for the last 2 to 3 years; 1.5 percent of the castings in the foundry were rejected, and customer rejections amounted to 0.7 percent. A breakdown of total scrap rejections for October 1944 (14,420 pounds) follows:

	Percent
Foundry rejections	51
Customer rejections	49

Reason	Foundry, percent	Customer, percent
Miss runs	8.6	-
Shrinkage	6.1	97.5
Hot tears	-	-
Mismatch	7.7	-
Slag and sand	8.3	1.4
Poor molding	2.0	.1
Gating and risering ..	35.5	-
Porosity	1.3	-
Cold cracks	30.2	-
Removal of risers	.3	-

The average castings produced were about 40 pounds. The largest casting made was 2-1/2 tons finished weight.

Eisengiesserei Rodinghausen, Menden

The steel foundry operated at Eisengiesserei Rodinghausen in Menden is similar to the majority of steel foundries in Germany and may be considered as typical of the smaller German steel-casting foundries. Their steel-casting department is usually only one part of the foundry, as other ferrous metals and, in some cases, nonferrous metals also are cast. At this foundry approximately as many gray-iron castings as steel castings were produced.

Mr. Becker, the owner-manager, was interrogated and stated that 150 men were employed in the steel foundry and that 700 tons of liquid steel was made per month to produce approximately 400 tons of castings. Maximum production was reached in June 1944, when 450 tons of castings were produced. The pre-war output of steel castings was about 300 tons per month, classified as follows: Railroad castings, such as journal boxes, cylinder-head covers, etc.; mine-equipment castings; tractor parts; and miscellaneous machinery parts. A number of castings produced during the war were typical stamp forgings, which had to be made as castings because of the limited forging capacity.

Castings were produced to the lowest strength requirements of 54,000 psi tensile strength and 20 percent elongation (DIN 1,681, class 31.81). Average properties obtained at the foundry were 64,000 psi and 25 to 30 percent elongation. Only carbon-steel castings were manufactured, and these were furnished in the annealed condition. The largest castings made had a shipping weight of 1 ton. The smallest weighed a few ounces.

Melting Practice

Four 2-ton side-blow converters were available for melting steel, though only one converter was used at a time. Cupola iron was produced in two 5-ton-per-hour cupolas operating 10 hours per day. It was the practice to operate one cupola one day and the other the next day. The converters were acid-lined with 12 inches of rammed lining on the side walls and an 18-inch rammed bottom. Lining material was purchased fully prepared except for the addition of water. It appeared to be a ground ganister with clay additions. This material was mixed with as little water as possible and still permit the material to be rammed. No silica bricks were used in the converter lining. From 50 to 60 heats were obtained from each lining. It took approximately 3 days to dry a lining. The converter had 6 tuyeres in a single row. The steel was made in the conventional manner, approximately 20 minutes being required to make a heat.

The cupola charge consisted of a high percentage of steel scrap, 10 percent coke, and 3 percent limestone. The cupola metal at the spout was about 1,200° C. (2,192° F.) and of the following composition:

	Cupola iron, percent	Converter steel, percent
Carbon	1.8	0.20
Silicon	1.7	.30
Manganese	.60	.60
Sulfur	.09	.09
Phosphorus	.07	.07

If the cupola iron was desulfurized, which was rarely, the sulfur content would be about 0.06 percent.

The tapping temperature of the steel was not known. Cupola and converter losses amounted to 19 percent. The ferromanganese and ferrosilicon were placed in the ladle without preheating, and 2 pounds per ton of aluminum was added to the ladle. A small amount of aluminum was added to the hand shanks also.

Molding

Most molding was done in a fine, natural bonded sand. The same sand, with a small percentage of dextrine, was used for cores. Most cores were produced on three core-blowing machines, the sand for which was very fine and consisted of:

	Percent
Silver (washed quartz) sand	57
Yellow (natural-bonded) sand	28
Sulfite lye (lignin)	6
Radoil (core oil)	9

Water content of the mixed sand was about 6 percent. The core blowers (Vogel-Schemmann) held about 1/3 cubic meter of sand. One woman core maker could produce 5 to 6 hundred 1-1/2-pound cores in 9 hours. There were 26 molding machines, but all sand had to be brought to the machines in buckets, and all molds had to be moved from the machine by hand or by overhead cranes. Castings weighing more than about 250 pounds were molded in chamotte.

In contrast with the antiquated molding methods and lack of production equipment, cleaning of castings was quite modern, with two table blasts, three room blasts, and three wheel abrators served by monorail. The cleaned castings showed exceedingly poor surfaces, with numerous scabs and much porosity. Many shrinkage cavities also were very prevalent. Seven vertical and horizontal saws were used to cut off risers. Risers of even 2 inches were sawed on the machines. Casting rejections were claimed to be only 1.8 percent in 1944. It was stated that sand and slag were the chief causes of rejections. It was evident, however, from observation of castings ready for shipment, that rough surfaces, scabs, and porosity were not causes for rejection. Gating and feeding practice was poor. Average weight of castings produced was 10 to 15 pounds.

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PART 8. - FOUNDRIES OF THE SAAR

Röchlingische Eisen-und-Stahlwerke, Völkingen

The Röchling Co. at Völkingen, near Saarbrücken, operates two foundries for the production of steel castings - (1) an aircraft foundry and (2) a heavy-castings foundry. The Rochling Co. also produced other steel products, such as ingots, rolled shapes, etc. Their over-all production was about 50,000 tons of steel per month. Approximately 700 to 750 tons per month of liquid steel was made for aircraft castings to produce 90 to 100 tons per month of rough machined castings, and 120 to 150 tons per month of liquid steel was poured into large castings to yield about 60 to 75 tons per month of castings ready for shipments. For the aircraft castings it took about 7 tons of molten metal to produce 1 ton of rough machined castings.

Approximately 99 percent of the production of the aircraft foundry was aircraft castings. The other 1 percent consisted of corrosion- and heat-resistant steel castings, the high-alloy steel for which was produced in a 1,000-pound acid-lined, high-frequency induction furnace. The furnace lining consisted of chamotte moistened with water glass (sodium silicate) and rammed into a steel form. The high-alloy steels were mostly made for heat- and corrosion-resistance castings for the chemical industry. A few propellers also were produced.

The large casting foundry produced 50 percent of its tonnage, or about 60 tons per month of submarine covers; the remainder went into miscellaneous castings, such as turbine covers, press castings, gears, and rock- or coal-crusher castings, the latter being made of 12 to 14 percent manganese steel.

Melting Practice

Steel for both foundries was produced in two basic electric furnaces of 6 and 7 tons capacity. For large castings, open-hearth steel was brought over from the ingot shop. The electric furnaces were used with rammed dolomite linings and finely ground rammed magnesite bottoms. The magnesite was slightly moistened prior to ramming. A sintered top layer was made by arcing on coke. When the plant was under full production, four heats were made per day in each furnace. A steel-melting practice similar to that used in Germany was employed. A heat required 5 to 6 hours, and the steel was under a white slag for 1 to 1-1/2 hours. Ferromanganese was added at slag-off time, and ferrosilicon was added 15 minutes before tapping. A small percentage of aluminum was added to the steel in the ladle, but the amount used was not recorded. No slag-viscosity tests or slag analyses were made; only the color of the slag was examined. The Ruff fluidity test was employed at the furnace; for aircraft castings, a 5-mm. diameter channel was used. The test mold was rammed up out of normal molding sand, and the mold was dried prior to use. For aircraft castings of 7 to 12 mm. section, the fluidity was required to run 320 mm. The temperature of the steel was determined in an empirical way by inserting a 8-mm. square rod into the bath for 5 seconds. If the rod melted in that time, the temperature was high enough for tapping. All the steel was bottom-poured. Hand shanks were filled from the bottom pour ladles.

As hot steel was required for the thin-walled aircraft castings, the roof like was rather low until the Krupp ring was used. The Krupp ring is a cast water jacket that is installed around each electrode and extends entirely through the roof. The exposed metal section is about 1 inch thick. Cold water is projected along the exposed section, which is approximately 2 inches wide. With the use of the Krupp ring, the life of the roof was increased from 25 heats to 150 heats per lining. The management was very enthusiastic concerning the value of the Krupp ring.

Molding

The facing sand for aircraft castings having sections less than 30 mm. was a green sand consisting of:

	Percent
Silver (quartz) sand	70
W. B. (a substitute for dextrine)	2-3
High-grade clay	3
Yellow (natural-bonded) sand	25
Moisture	5

For aircraft castings of a minimum wall thickness of 30 mm., a washed quartz sand with 12 to 15 percent clay was used.

The heavy castings were produced in the various grades of Form Masse chamotte. The green sand and the Form Masse preparation were poorly handled, there being no sand-conveying equipment to aid in preparation or distribution.

Two types of alloy steels were used for the aircraft castings:

	Percent						
	C	Mn	Si	P	S	V	Cr
MV	0.22-0.28	1.50-1.60	0.5	0.03 max.	0.03 max.	0.08	-
CV	.22- .28	.40- .60	.5	.03 max.	.03 max.	.08	1.5-1.8

Approximately 90 percent of the aircraft castings were out of the manganese-vanadium grade. The castings were cleaned and given a normalizing treatment followed by rough machining. All aircraft castings were 100 percent machined or ground. The castings then were heated to the quenching temperature in an electric continuous tray-type furnace, quenched in water in small batches, and immediately placed in a gas-fired, recirculating, tempering furnace and tempered to the following minimum properties:

Tensile strength	128,000
Yield point, psi	106,000
Elongation, percent	20

The castings were then placed in an oil bath and heated at boiling-oil temperature for 1 to 1-1/2 hours, followed by sand blasting and visual inspection for oil seaps by cracks or pourous metal. The castings were then magnetically inspected prior to shipment. During the period of maximum production, 300 men were employed in the cleaning room for the production of 100 tons per month of aircraft castings (780 man hours per ton of castings).

The aircraft castings were cast to 10 mm. minimum wall section and some of them were machined down to 1/8 inch thickness. The average loss from defective castings was 20 percent, divided as follows: 4 percent attritubed to foundry, 4 percent for off-analysis and porous steel, 5 percent for improper cutting of risers, grinding, and quench cracks, and 7 percent for mistakes in rough-machining. In the large-casting foundry the defective castings amounted to 5 percent, with the defects in the following order of frequency: (1) Porosity, (2) slag and inclusions, (3) shrinkage, and (4) hot tears.

The casting surfaces of most castings were not good, but nearly all castings were rough-machined prior to shipment.

The management claimed that Rochling was the only company producing alloy steel castings in quantity in the Saar area.

Saarländisches Stahlwerke Dingler, Karcher Co., Saarbrücken

The Dingler, Karcher Co. is a medium-size steel foundry engaged in peacetime in the production of miscellaneous steel castings for railroads and the mining industry. Approximately 50 percent of the production was locomotive castings, according to Messrs. Karcher and Lender, management officials. Valves, fittings, gear blanks, etc., also were produced. During the war the company produced about 1,000 tons per month of finished castings. A 50-percent yield of the pouring weight was normally obtained. The largest portion of the production went into 105 and 150 mm. shells, of which 500 to 600 tons per month were made. Tank track shoes were produced at the rate of 150 tons per month, and the remainder consisted of drive wheels for tanks, machine-gun housings, heavy truck axel housings, and a small percentage of mine and railroad castings. As many as 30,000 axol-housing castings were made from the same pattern. These averaged 22 pounds in weight and contained a thin-walled section of 3/16 inch.

Melting Practice

The company operated a 1-1/2- and a 3-ton basic electric furnace, two 2-1/2-ton converters, and three cupolas. The basic electric practice was similar to that used throughout Germany. On special castings, when hot tears were encountered, two or three carbide slags were used to bring the sulfur content down to 0.02 percent. If thin-walled castings were to be poured, 75 percent ferrosilicon was added to the ladle, but no aluminum additions were made. Steel for castings of normal wall section was deoxidized in the ladle with aluminum. No record was kept of the quantity of aluminum added. Lining life consisted of 30 heats per side wall and 50 heats for roofs when steel for thin-walled castings was being made. A 12 to 14 percent manganese steel was the only alloy steel produced.

The total cupola-converter loss was 18 percent. Only occasionally was the cupola metal desulfurized. A drop in sulfur from 0.10 to 0.05 percent was obtained when desulfurization was carried out. An average blowing time of 20 minutes was necessary, and 22 heats were produced in a day. Life of the rammed chamotte lining was 130 heats.

Molding

Molding materials consisted of a natural bonded Rosenthal sand, in which all castings up to 10 mm. wall thickness were molded. This was a green sand with a maximum of 5 percent moisture. The molds were permitted to air-dry. Castings of sections of 10 to 40 mm. were molded in Belgian sand, which is a natural bonded sand. The molds were oven-dried. Castings of wall sections over 40 mm. were molded in Form Masse chamotte. About one-third of the production was in chamotte, one-fifth in Rosenthal green sand, and the rest in Belgian sand. Facing sand for track shoes was Rosenthal, to which was added 2 to 3 percent clay (a synthetic bentonite) and a 10-percent quartz sand to increase the hot strength of the sand. Cores for tank track shoes were produced on two core blowers. No risers were used on these castings. The "as cast" weight was 52 pounds, and the weight of the casting ready for shipment was 42 pounds. The track shoes were water-quenched, 200 being quenched at a time. Quenching equipment was poorly mechanized, the distance between it and the furnace being 50 feet.

Scrap resulting from defective castings was 4 to 5 percent, scabbing and hot tears being listed as the primary causes. An average of 15 percent scrap was obtained on tank track shoes and 5 to 6 percent scrap on the truck axle housings. The surface appearance of all castings was poor, showing metal penetration and surface porosity.

The shells were produced in permanent molds. Six 105 mm. shells were produced in a mold, whereas only four 150 mm. shells were made in a mold. The molds were of a good-grade cast iron containing not over 0.2 percent phosphorus. The shells were cast of 0.40 to 0.45 percent carbon converter steel. No heat treatment was given the shells.

Foundry production reached its peak in July 1944 and then tapered off, and the foundry closed in November 1944 owing to lack of electricity and gas and too many air raids. The foundry was about 85 percent in operating condition.

Heckel-Werke, Rohrbach

Management representatives interrogated at the Heckel Co. were Dr. Vohmann, technical director, and Mr. Leffer, foundry superintendent. The steel foundry of this company produced 700 tons per month of steel castings during 1944, of which 400 tons per month were 105mm. Howitzer shells, or about 18,000 to 20,000 shells a month. Each shell weighed about 42 pounds in the "as-cast" condition, or 32 pounds as rough-machined. Tractor and trailer parts for the German army, such as brake housings and covers, consisted of about 100 tons per month, and the remaining 200 tons per month were castings for mine cars, trams, belt conveyors, skip hoists, and other mine equipment. The latter type of castings was the normal peacetime production, which totaled 250 to 300 tons per month. The foundry stopped pouring steel early in February 1945 because of lack of supplies. The foundry is not damaged.

Melting Practice

The foundry operated one 2-ton-capacity, plant-built, Rennerfelt electric-arc furnace, which contains two electrodes that enter the furnace sides on opposite sides and one electrode that enters the furnace through the top. The side electrodes entered at about a 30° angle up from horizontal. The furnace was usually overcharged to 3 or 4 tons. The management claimed that with this furnace the electric energy is transformed into heat very simply and scientifically, so that the furnace can operate efficiently without requiring an excessively rated transformer. An average of 750 Kw.-hr. per ton was obtained. Only two automatic regulators are required for the two-phase arc. The heating flame is vertically adjustable and independent of the charge. The furnace operates quietly, without violent surges in the power. Dr. Vohmann described the arc produced as a flaming arc, as it extended vertically downward considerably below the junction of the three electrodes. The furnace was rammed with a basic lining of dolomite, and a silica-brick roof was used. The lining life was 50 heats for the side walls and 70 heats for the roof. The walls had to be lined with considerable care. Normal basic electric practice was used. Finished steel contained about 0.06 percent phosphorus and sulfur each.

Two acid-lined, side-blow converters and two cupolas also were used alternately for making steel. The life of the rammed chamotte lining was about 70 heats. The cupola metal was about 1.6 percent silicon, 3.00 percent carbon, 0.10 percent sulfur, and 0.08 to 0.10 percent phosphorus. A converter blow lasted 14 to 16 minutes, and 22 blows were made in a day. The ferromanganese was preheated to 1,000° to 1,100° C. (1,832° to 2,012° F.). Studies indicated that by preheating the ferromanganese the manganese loss was reduced from 20 to 5 percent. Ferromanganese was added to the converter and ferrosilicon was added cold to the ladle.

The shells were manufactured of converter steel. No attempt was made to desulfurize the steel, as the German government permitted phosphorus plus sulfur to be present up to 0.25 percent. Analysis of the steel for shells was 0.36 to 0.44 percent carbon, 0.32 to 0.65 percent manganese, 0.60 to 1.2 percent silicon, 0.085 to 0.13 percent sulfur, and 0.10 to 0.12 percent phosphorus. Property requirements were a tensile strength of 71,000 psi and an elongation of 3 percent. A fragmentation test required 420 fragments larger than 5 grams. The shells were tested under a pressure of 10,500 pounds.

For the most part, steel production consisted of carbon steels of 0.3 to 0.4 percent carbon. A small amount of 12 to 14 percent manganese steel was produced, as was a Mn-Si steel for gears of 0.35 percent carbon, 1.2 percent manganese, and 0.7 percent silicon. Tensile properties of this steel were strength 78,000 to 85,000 psi and elongation 14 to 22 percent.

Molding

Molding consisted of 15 percent green sand (air-dried), 40 percent dry sand, and 45 percent chamotte. The shells were produced in cast-iron molds.

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A wash consisting of graphite and fine chamotte (Edelschlichte) was used on the green-sand molds as well as on the chamotte. The wash was applied in a thick coat.

Defective castings gave 8 to 10 percent scrap. Shell scrap was 10 percent. The surface of all castings was unsatisfactory. The riser practice was poor, as in the machine shop many castings showed dhrinkage. Most castings contained pin-hole porosity in spite of the 2.2 pounds of aluminum added per ton.

Cast-iron and steel castings were produced in the same shop, though the sands were kept separate.

PART 9. - STEEL FOUNDRIES IN THE FRANKFURT-STUTTGART AREA

Buderius Eisenwerk, Wetzlar

The Buderius Eisenwerke at Wetzlar produces many steel products, but one portion of the works was devoted to the manufacture of centrifugally cast guns and static steel castings. The production of these units was housed in a foundry building containing two 2-ton electric-arc furnaces, three centrifugal casting machines, and two production units for the casting of tank track shoes. Management representatives interrogated were Dr. Steinweger, general manager, and Mr. Kohler, foundry superintendent.

The specialty of the company was the vertical casting in quantity of gun barrels 2 to 4 meters (6.5 to 13 feet) in length and the experimental production of 6-meter (19.5-foot) gun barrels. These guns were produced to fire 75-mm. shells. Approximately 350 tons per month of guns were produced. The largest number produced in one month was approximately 450. The centrifugal casting machines were driven by electric motors. The dirving mechanism was at the base of the machine and was housed in a concrete pit. The base of the cast-iron mold was bolted to the base of the revolving table unit. The mold was maintained in a true vertical position by two sets of adjustable rollers attached to the pit walls and rotated on roller pads on the mold located near the top and middle of the mold. There were four rollers at each position. The position of the rollers could be adjusted so that molds of various sizes could be used. The machines were capable of revolving 20 tons of mold and casting at speeds from 100 to 1,500 revolutions per minute.

The molds for the gun castings were heavy-walled. For the 4-meter-long casting, a mold of approximately 16 tons was required to produce a casting weighing 1.6 tons. The ratio of wall thickness of casting to wall thickness of mold was approximately 1 to 6-8. The mold walls were tapered, the heaviest section being at the gun-breech positions.

The molds were lightly coated with a wash consisting of finely pulverized quartzite, 6 percent Al_2O_3, and 2 percent bitum. The bitum was purchased in either liquid or solid form from Habner Bergbau, Dortmund, and is a derivative of bituminous coal. The wash had a maximum grain size of 0.001 mm. and prevented the castings from fusing to the mold walls. The bitum is volatile, and the gas creates a reducing atmosphere which, according to company officials, prevents the particles of splashed steel from oxidizing.

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A pouring or runner box was securely fastened to a cover plate located over the top of the mold. The runner box was lined with a rammed chamotte and contained a baffle to act as a slag trap.

Steel was poured from a bottom-pour ladle into the basin in the runner box; it ran under the baffle and down a funnel spout into the mold. The funnel spout was 3 inches long and 1-1/8 inches in diameter. The lining of the funnel consisted of a sleeve 3/16 inch thick, and the opening through which the steel ran was 3/4 inch. The base of the mold was rammed with a chamotte plug.

The primary precaution in pouring the mold was to make certain that the stream of steel retained the form of a column of steel from the pouring spout to the bottom of the mold and that it fell directly in the center of the mold. Interrupted streams caused undue spattering, which caused hot steel to adhere to the mold walls. The mold was revolved at 200 r.p.m. during the early part of pouring while it was filled for approximately one-third of its length. By the time pouring was completed, the mold was operating at 1,400 r.p.m. A revolution counter, recording in revolutions-per-minute, was installed on the control panel. Pouring time was 3 to 4 minutes. Spinning time after pouring was approximately 15 minutes, or until solidification of the steel was complete. The total time from the beginning of pouring until the casting was ready to be removed from the mold was about 24 minutes. The temperature of the casting at the time it was removed from the mold was approximately 750° C. (1,382° F.). The gun castings were then placed in a sand pit, where they were permitted to cool slowly for 100 hours. The temperature of the casting when it was removed from the sand pit was 200° C. (392° F.). Heat-treatment of the tubes after rough machining consisted of quenching and tempering. The low-manganese steels were water-quenched and the nickel-chromium steels were oil-quenched.

Finish requirements for machining permitted 10 to 15 mm. on the outside surface. This was certainly necessary in view of the extreme porosity of all outside surfaces. The center of the gun was bored out. Only approximately the upper third of the gun contained a hollow central portion. This opening was circular in cross section but parabolic in length. The only tubes that could be made with a cast hollow bore were 2 meters (6.5 feet) or less in length. Such tubes, in the "as-cast" condition, had a wall section of 3 inches at the base of the tube and a 2-inch section at the top of the tube. The 6-meter guns in the "as-cast" condition had a breech of 12 inches in diameter and a nozzle 7 inches in diameter. The diameter of the opening at the nozzle was 3 inches.

It was stated by company officials that the forging weight for the 4-meter (13-foot) guns was 2,200 pounds, whereas the centrifugal casting weighed 1,540 pounds. The weight saving was directly reflected in machining time in view of the 660 pounds of steel that did not require removing. Scrap rejection was approximately 5 to 6 percent.

It was stated that peacetime use of the vertical centrifugal machines would be in the production of ingot molds and railroad freight-car axles.

Approximately 700 tons per month of tank track links of various sizes for weapon carriers were produced. These were made in green sand containing a high proportion of clay. The molds were produced on jolt ram machines and were placed on a roller conveyor for transportation to the pouring floor. Nothing novel was noted in the procedure. Melting and molding practices were similar to that previously reported.

Eisengiesserei Streicher Asperg, Nr. Stuttgart

Eisengiesserei Streicher operates two foundries - an iron foundry in Cannstatt-Stuttgart, from which the company derives its name, and the steel foundry in Asperg, which is the only steel foundry in the State of Württemberg.

The technical and commercial manager was alfred Peitzmann, who was the only one interrogated at the plant. The average production of steel castings in 1944 was 650 tons per month, whereas peacetime production averaged only 250 tons per month. Castings produced before the war were for railroad equipment, such as crossheads, parts of freight cars, and general repair parts; valves and valve parts for gas plants; frames for presses; and castings for various heavy machines built in Württemberg. War production was 200 tons of 120 mm. mortar shells and 450 tons of brake housings for tanks and railroad castings. The company employed 550 men and women during the war.

The plant is not damaged and could start operations at once.

Melting Practice

The melting equipment consisted of one 3-1/2-ton acid electric furnace, two cupolas, and two converters of 2-1/2 to 3 tons capacity. The latter two were used alternately, day by day. The charges in the cupola consisted of 70 percent steel scrap with a melting loss of 7 percent. A typical analysis at the spout was 2.9 percent C, 1.6 percent Si, 0.6 percent Mn, 0.08 percent P, and 0.09 percent S.

The cupola iron was desulfurized with powdered, fused soda ash, and the sulfur content was reduced to 0.06 percent. After blowing was finished and ferrosilicon and ferromanganese were added, the end analysis was 0.15 percent C, 0.45 percent Si, 0.60 percent Mn, 0.10 percent P, and 0.06 percent S. Melting loss in the converter was estimated at 10 percent. Manganese was added in the converter following the customary practice of dipping in water first in order to disperse slag by explosion. The ferrosilicon was added in the ladle. The converter linings consisted of rammed chamotte, and two extra shells were available to assure slow and perfect drying. A typical converter slag analysis was 2 percent CaO, 67 percent SiO_2, 7.7 percent MnO, 17.0 percent FeO, and 4.4 percent Al_2O_3.

The electric furnace (a Siemens side-charged type) is one of the very few acid-lined furnaces in Germany. The lining life was 120 to 130 heats, and the roof life was 500 to 600 heats. The lining was monolithic. The melting practice was semioxidizing, and in the last year the use of limestone in the finishing slag was discontinued. Analysis of the finished slag after tapping, when limestone was used, was as follows: 8.8 percent CaO, 66.3 percent SiO_2, 5.4 percent MnO, 7.6 percent FeO, and 10 percent Al_2O_3. The current consumption averaged 700 kw.- hr. per ton. Only carbon steels were produced at this plant.

Molding

Of the 650 tons of steel castings produced per month in 1944, 150 tons were cast in chamotte, 300 tons in green sand, and 200 tons of shells in cast-iron molds. For production jobs, four core-blowing machines were available. The shell cores, about 2 feet long, were blown on these machines, placed on special core dryers, and, after baking, were dipped in a core wash. Approximately 600 shell cores were made by two girl operators in 9 hours. The core boxes were rubber-lined with vulcanized rubber applied to the inside of the box; the hard rubber had the exact contour of the core. It is claimed that this rubber-lined core box maintained its true dimensions much longer than a metal core box. When it does finally wear out, the old rubber lining can be removed and a new rubber lining inserted. The cast-iron molds for the shells had 6 impressions, and metal entered the mold through one central runner box which was placed on top of a runner core. The iron used for making the molds was low in sulfur and phosphorus; the latter should not exceed 0.20 percent. Specifications for the shells were as follows: Minimum tensile, 85,000 lb./sq. in., and 3 percent elongation. No annealing or heat treating were required. The fragmentation test should give 750 fragments over 5 grams per shell. The analysis was approximately C, 040 percent; Si, 0.80 percent, and Mn, 0.80 percent. The shells were rough-turned by chucking from the inside. Tungsten carbide tools were used. The weight of an "as-cast" shell was 32 pounds.

All castings were poured with bottom-pour ladles; the largest casting weighed 5 tons, 7-1/2 tons of steel being required to pour it. One electric furnace and one converter charge were required to pour the casting. Average casting weight was 32 to 45 pounds. The scrap reports showed an average of 5 to 6 percent, of which 4 percent was traceable to general molding and 2 percent to steel making. The shell scrap was 10 percent. The scrap losses of valve bodies due to porosity was extremely low in spite of a pressure test of 1,500 to 2,000 lb./sq. in. The management claimed that melting the steel in the acid-lined furnace contributed to the success of the process. Being located in a rural area, the plant was obliged to have its own coke/gas generator; gas was used for heat-treating and annealing castings. Gating and risering of castings was orthodox, and casting surfaces were very poor.

PART 10. - REICHSWERKE, ALPINE MONTANTEBETRIEBE HERMANN GOERING, LINZ, AUSTRIA

The Reichswerke Hermann Goering consisted of a nitrogen gas plant, an ore-concentration plant, blast furnaces and coke plant, and the Eisenwerke Oberdonau, which consisted of an ingot plant, rolling mills, and a steel foundry. The Reichswerke has been given a new name since hostilities ceased, and it is now known as Vereinigte Eisenwerke, Oesterreich.

During the days of peak production, approximately 10,000 people were employed at the works, of which 350 worked in the melting shop and about 600 in the steel foundry. The officials of the Company interrogated were director Klepp, in charge of the melting shop, and Mr. Zeyringer, foundry manager.

Melting Practice

The melting shop contained three 20-ton and one 25-ton basic electric furnaces and one 200-ton basic open-hearth furnace. Approximately 14,000 tons per month of steel was produced in this shop, most of which was alloy steel that went into the production of ingots. About once a week 20 to 50 tons of steel was sent from the melting shop to the foundry to make up for the lack of molten-metal capacity in the foundry.

The corner stone for the plant was laid in 1937, but the first charge was melted in January 1943. The plant was the latest steel foundry to be built by the German Government. The foundry produced 1,000 to 1,200 tons per month of finished castings up to July 1, 1944, when during the 2 days' bombing attacks, the transformers on the electric furnaces were smashed and casting production dropped to 600 tons. Production then decreased to 200 tons per month until the American troops entered the area on May 2, 1945. By this time, the transformers for the electric furnaces had been repaired.

The casting production consisted of 50 percent armor castings for the Panther and Tiger tanks, such as turrets, shields, front pieces, gear housings, drive wheels, idler wheels, etc.; 25 percent track shoes for tanks, armored cars, and weapon carriers; and 25 percent automotive truck castings.

The steel foundry contained two 5-ton basic electric furnaces (Demag) and had prepared pits for a 6-ton and a 15-ton electric furnace that never were installed. Also, two cupolas and two 2-ton acid-lined converters were used alternately for steel production. The melting practice for both electric and converter furnaces was similar to that used throughout Germany, except that the furnaces were lined with magnesite brick. The usual two to three slags were removed in the electric furnaces. Kilowat hours per ton averaged between 700 and 800 for carbon steel and 800 to 900 for alloy steel. No studies on slag, as to composition or viscosity, or fluidity tests were made. The converter steel was a plain carbon steel of about 0.40 percent carbon and was used for track shoes. A desulfurization practice of 25 pounds per ton of soda ash was carried on with good results, and the sulfur content was lowered from about 0.04 to 0.02-0.03 percent. The sulfur content of the cupola metal was low, because a special coke very low in sulfur was used. The phosphorus content was high, being 0.16 percent maximum.

The electric-furnace steels were primarily alloy steels of the Cr-Mo, Cr-Ni, Cr-V type. All armor castings required phosphorus plus sulfur to be under 0.04 percent. A typical log heat of a 5-ton electric furnace is given in table 24.

Molding

Two types of molding materials were used - (1) green sand and (2) chamotte. The truck castings and the track shoes were made in green sand, and the tank castings were produced in chamotte; thus, approximately 50 percent of the production was molded in chamotte. The chamotte practice was similar to that normally used in Germany, except that chamotte as received constituted the facing sand. The green-sand mixtures used are given in table 25. The green sands were separated from the chamotte.

All green-sand mixes were shaken out together and re-used as backing sand.

The plant had the most modern sand-handling system in Germany. All operations could be followed on a Calor-Emag system, from which all operations were controlled. Lights on the flow-sheet control panel indicated the machinery in operation. The sands were dried in a continuous gas oven. In 24 hours 18 to 20 cubic meters of sand was dried from 12 to 14 percent moisture to 0.6 percent moisture. The dried sand was placed in four bins. The sand was then drawn off by wheelbarrow and transported to the mixing mullers. This operation was the only manual operation in the sand system. The reason for nonmechanization was that it was desired to mix the sand in volume lots, and a wheelbarrowful was claimed to be an excellent volume measure.

The facing sand was mulled in two 1/2-cubic meter mullers and then placed in four bins, where it was distributed to the molders in trays by crane. It was claimed that molders used too much facing sand if it was distributed by conveyors.

The old sand at the time of shake-out went into 12 bins at one side of the molding and pouring floor. The chamotte went into bins under the center of the floor. These bins fed an under-floor conveyor to a magnetic separator and then either to disposal or to two small 2-1/2-cubic meter bins, from which it was remulled and distributed by overhead conveyor to 30 molding machines and two 5-ton roll-over and two 7-ton roll-over machines. The chamotte was also drawn from the under-floor bins over a magnetic separator and through rolls and then either rejected or remulled and distributed by the overhead conveyor to the 5-cubic meter bins at each molding machine. No method of separating fines or reclaiming the molding material was in use. For this reason they used 1,000 to 1,200 tons per month of molding material, or 1 ton of molding material for every ton of castings produced. It was again confirmed that there was no organization in Germany constructing sand-reclaiming equipment.

Four core-blowing machines were available for blowing cores for the track shoes and other castings. Core mixtures were as follows:

Rammed cores	Parts
Quartz sand	60
Molding sand	10
Fine chamotte	30
Core oil	1
Mogul	5
	106

Blown cores	
Quartz sand	12
Core oil	4-1/2
Clay	3
Sulfite lye	2

TABLE 24. - Typical heat log of 5-ton basic electric furnace, Reichswerke, Herman Goering

Charge:

	Pounds
B12 alloy steel scrap	4,000
Mn steel scrap	600
Foundry returns	5,400
	10,000

Time	Remarks	Analysis, percent
0.00	Finished charging, 50 lb. coke, 60 lb. ore.	
0.05	Power on	
2.45	160 lb. lime	C 0.50; Mn 0.91; P 0.047; S 0.028; Cr 0.80; Ni 0.31; Mo 0.15; V 0.06
3.05	40 lb. ore	
3.15	First slag removed	
3.20	160 lb. lime, 40 lb. fluorspar	
3.25	60 lb. ore	
3.30	40 lb. ore	
3.40	Second slag removed	
3.50	160 lb. lime 60 lb. ore, 40 lb. fluorspar	
4.05	40 lb. ore	C 0.33; Mn 0.22; P 0.025; Cr 0.22
4.45	Third slag removed	
4.50	160 lb. lime; 40 lb. fluorspar	
5.00	100 lb. FeMn (41% Mn)	
5.10	290 lb. FeCr; 16 lb. FeMo	
5.30	Third analysis	C 0.30; Mn 0.71; P 0.026; Cr 2.14
6.00	40 lb. pig iron	
6.10	20 lb. FeSi	
6.15	15 lb. FeV 6 lb. aluminum (1.2 lb. per ton)	
6.20	Final carbon	C 0.36
6.25	Tapped 2 lb. aluminum to ladle (0.4 lb. per ton)	

Current consumption: 940 kw.-hr./ton

TABLE 25. - Green-sand mixtures Reichswerke, Herman Göering

1. Sand for chain links for panther tank:
   (Electric furnace steel with 1.2-1.6 percent Mn)

   150 parts heap sand
   75 parts silica sand
   7 parts GEKO (synthetic bentonite, Ullrich, Leipzig)
   9 parts powdered hard coal

2. Sand for tank covers, skin-dried.
   (Electric furnace steel containing either CrNi or CrMO)

   75 parts green molding sand
   150 parts silica sand
   7 parts clay
   12 parts dextrine

3. Standardized sand for chain links
   (Converter steel with 0.18-0.27 percent C; 0.40-0.60 percent Mn)

   350 parts heap sand
   70 parts green molding sand
   5 parts GEKO

4. Sand for heavy truck parts (Converter steel).

   150 parts heap sand
   75 parts green molding sand
   5 parts GEKO

Moisture on all four sands averaged 5 percent.
Silica sand (not washed, with 1-2 percent natural clay)
Schnaittenbach near Amberg, Bavaria
Green sand (15-20 percent clay), Raitz, near Brunner, Austria.

The casting yield was 40 percent for small parts for trucks to 60 percent for large castings. Castings of a few ounces to those weighing 2 tons were produced. The defective casting loss was 4 to 5 percent. In special items, such as tank shoes, a loss of as much as 23 percent was experienced. It was claimed that slag was the main cause for rejection, with hot tears in converter steel being prominent.

In general, the casting surfaces were fairly good - in fact, about the best seen in Germany. Some pin-hole porosity and metal penetration were observed. Roller conveyors fed out from all the molding machines, and the foundry in general was the best mechanized seen in Germany.

Cleaning, welding, and heat treatment of castings was standard practice. The quenching and tempering equipment was housed in a separate building.

APPENDIX 1. - INSPECTION REQUIREMENTS OF STEEL CASTINGS FOR AIRCRAFT, ASSOCIATION OF AIRCRAFT, BERLIN

A. Requirements

1. Type and grade of steel. Details may be found in section F below and in Appendix 2.

2. Surfaces must be smooth, free of cracks.

Minor surface blemishes are permitted. Welding is permitted under certain conditions. The inspector must be notified and his approval obtained. Castings must be welded prior to final heat treatment. Welding rods should be selected that will give the welded area, after heat treating, the properties required by the casting. If castings require welding repeatedly in the same section, then proof must be furnished of the soundness of the weld. If no welding is permitted, then all drawings pertaining to the casting must be marked to the effect that welding of the area is prohibited.

3. Partly machined steel castings shipped to purchaser are to be tested by heating in oil or by magnetic testing for cracks. Welded castings must, however, be magnetically inspected. Oil testing consists of heating the castings in oil at a temperature of 140° to 150° C. (284° to 302° F.).

4. All weights and dimensions specified must be met.

B. Sample Castings

Sample castings must be submitted and approved by customer before proceeding with order. Test specimens must also be cast with sample. Complete report of the properties after heat treatment must be furnished in duplicate and extra test pieces furnished for purchaser check tests if desired.

C. Testing

1. Type of test bar and location on casting must be specified on the drawing if bars are attached.

2. Castings without test bars attached must be heat-treated with the separately cast bars. Every casting is to be Brinell-hardness tested. If the wall section varies greatly, both heavy and light section should be tested. The hardness of the lightest section may not exceed the upper limit of tensile testing by 10,000 psi when the hardness is multiplied by the factor specified. Out of every lot of 50 castings, at least one must be tested to destruction; for this, a defective casting may be used. Sections of this casting are used for tensile test, fracture test, and, in case of abnormal fracture or when specified, impact-test specimens also are to be prepared. If test bars fail to meet property requirements, castings from the heat must be reheat-treated and retested. If two or more heat treatments are necessary, castings are to be picked at random and checked for Brinell hardness.

3. Castings with test bar attached must be Brinell-tested in both light and heavy section if the section varies greatly. The tensile strength, as

calculated from the Brinell hardness, must be at least 5,000 psi over the minimum strength required. Hardness of the thinnest wall may exceed, up to 10,000 psi, the upper limit of the calculated tensile strength. If hardness is not within limits, the castings may be reheat-treated. One casting out of 100 must be tested to destruction. After the first three lots of 100 each are tested, one casting out of 200 may be selected for testing. Defective castings may be used for this test. Reheat-treating and retesting are permitted. Castings reheated more than once require only 5 percent of the castings to be rechecked for hardness.

D. X-Rays

The number of castings and the section of the casting to be X-rayed must be shown on the drawing. If not specified, only 1 percent of the castings is to be X-rayed.

E. Miscellaneous Requirements

1. Changes in specifications must be agreed upon by both foundry and customer. Additional testing will be done only upon request.

2. Foundries may be made partly or fully responsible for the testing of castings without the presence of the inspector.

3. Castings conditionally rejected may, after proper repairing or treatment, be submitted again for approval.

4. All castings must bear heat numbers, final-inspection stamps, and stamps showing approval of welded and X-rayed areas.

5. A certified test report signed by a company official and by the inspector must be furnished.

F. Chromium-Molybdenum Cast-Steel Requirements

Class:	1811.5	1811.6	1812.1	1812.6
	0.23-0.30 C	0.35-0.50 Si	0.18-0.28 C	0.35-0.50 Si
Composition:	0.50-0.75 Mn; 0.025 S max.; 0.2-0.3 Mo	0.035 P max.; 0.8-1.1 Cr;	1.0-1.3 Mn; 0.02 S max.; 0.25-0.35 Mo	0.03 P max.; 1.4-1.8 Cr;
Heat treatment:	Annealed	Hardened	Annealed	Hardened
Tensile strength, psi:	106,000 to 128,000	128,00 to 156,000	-	156,000 to 185,000
Yield strength, psi:	78,000	100,000	-	135,000
Elong. L = 5 dia., percent:	0-12	6-8	-	5-8
Red. of area, percent:	Approx. 40	Approx. 30	-	Approx. 35
Brinell hardness:	217-269	269-321	-	321-388
Diameter of ball impression, mm:	4.10-3.70	3.70-3.40	-	3.4-3.1
BHN to tensile factor:	0.34	0.34	-	0.34
Special property:	Weldable; after welding, tensile strength 85,000		Weldable; after welding, tensile strength 92,000	

APPENDIX 2. - COMPOSITION, HEAT TREATMENT, AND PROPERTIES OF VARIOUS CLASSIFICATIONS OF CAST STEELS, RUHRSTAHL ANNENER GUSSTAHLWERKE

TABLE A. - Steel castings for aircraft

Mark	Ni	C	Mn	Si	Cr	Mo	V	P	S	Heat treatment, °C.	Yield, 0.2 percent	Max. strength	Elong. L=5D	R of A, percent	Impact, mkg/cm^2
CV	-	0.23	0.50	0.35	0.90	-	max.	max.	max.	Anneal 950					
		.28	.70	.40	1.10		0.20	0.02	0.02	Water harden 880–910					
										Temper. 500–550	90–100	100–115	8–12	25–35	3
										Temper. 600	75– 85	90–100	9–12	35–45	11–13
										Temper. 650	55– 65	70– 80	15–18	40–50	15–20
										Air cool 700	55– 65	65– 75	12–16	40–50	10–12
CM	-	.23	.50	.35	.80	0.15	-	max.	max.	Anneal 950					
		.28	.75	.50	1.10	.25		0.02	0.02	Water harden 880–920					
										Temper. 500	80– 95	90–105	12–15	35–45	8–10
										Temper. 550	65– 75	75– 90	13–16	40–50	14–16
										Air cool 600	50– 60	60– 70	12–16	40–50	10–12
MV	-	.23	1.30	max.	-	-	.08	max.	max.	Anneal 950					
		.30	1.70	.50			.15	0.035	0.035	Water harden 880–920					
										Temper. 550	70	90–105	8	(30)	(3)
										Temper. 600	55	75– 90	12	(40)	(3)
										Air cool 650	60	65– 75	18	50	11
CMS	0.4	.20	1.10	.30	1.40	.25	-	max.	max.	Anneal 980					
		.25	1.30	.40	1.80	.35		0.02	0.02	Water harden 880	90	110–130	8	(35)	3
										Temper. 440–500					
GAS	-	.18	1.10	max.	1.30	-	0.15	max.	max.	Anneal 900					
		.26	1.40	0.50	1.70			0.025	0.025	Water harden 860	90	110–130	6	(30)	+20° 3 -45° 1.5
										Temper. 440–500					

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TABLE B. - Hydrogen pressure-resisting and high-temperature steel castings

Mark	Ti	C	Mn	Si	Cr	Mo	V	Heat treatment, °C.	Yield, 0.2 percent	Max. strength	Elong., percent L=5D	Impact, mkg/cm²	Creep strength
W6H	0.30-0.40	0.16 .22	0.50 .60	max. 0.40	2.50 2.70	0.20 .30	0.70 .85	Oil harden 1,020 Temper. 680	-	70	15	12	560° 17
W6HDm HM1G	-	.10 .15	.50 .70	1.10 1.20	1.60 1.80	.20 .30	.30 .35	Oil or air harden 1,020 Temper. 680	30	55-65	18	4	500° 10,570° 545 550° 7,600° 307
W6HLm HM2G	-	.10 .16	.30 .50	1.20 1.60	1.50 1.80		.25 .35	Oil or air harden 920 Temper. 680	30	55-65	18	4	500 9,570 5 550 6,600 3
W6HFm N5C	-	.12 .18	.30 .60	.20 .50	2.50 2.80		.10 .20	Oil or air harden 920 Temper. 680	25	50	22	12	
W6HKm N9	-	.18 .25	.40 .55	.30 .50	2.60 2.80	.20 .30	.45 .50	Oil or air harden 920 Temper. 680	50	80	14	8	
W6HL LIG	-	.15 .20	.60 .80	max. .45	1.00 1.20		.20 .30	Oil or air harden 920 Temper. 680	30	50	18	4	400° 19 450° 14 500° 10
W6HMm N8A	-	.18 .25	.30 .50	.20 .50	2.00 2.30		.20 .30		40	60-75	16	12	
W6HOm HMOG	-	.08 .15	.30 .50	1.40 1.70	1.50 1.80				30	55-65	18	4	500° 8 550° 4 600° 2 650° 1

TABLE C. - High-temperature steel casting

Mark	K list No. R-Warren No.	C	Mn	Si	Cr	Mo	V	Heat treatment, °C.	Yield, 0.2 percent	Max. strength	Elong. L=5D	Impact, mkg/cm2
W1		0.20	0.60	0.40	0.70	0.65	-	Air harden 900	45	60-70	15	4
		.25	.70	.45	.90	.75		Temper. 700				
WA1C		.20	.80	.30	.80		0.08	Air harden 1,000	28	50	20	5
		.27	1.00	.50	1.00		.15	Temper. 670				
WA1S		.20	.90	.30			.25	Air harden 920	30	52	20	5
MnVstg. 52/082		.28	1.20	.60			.35	Temper. 670				
W2		.20	.60	.40	.70	.45	-	Air harden 900	45	60-70	15	4
		.25	.70	.45	.90	.55		Temper. 650				
			Ni .5									
WA2S		.20	.50	.30	.90		.22	Air harden 1,000	32	55	20	5
CrV Stg.55 D82		.28	.80	.50	1.20		.28	Temper. 670				
W3		.13	.60	.40	.50	.28		Air harden 900	28	50	20	6
		.18	.70	.45	.70	.35		Temper. 680				
W3M		.18	.60	.40		.27		Air harden 920	25	45	22	6
		.23	.70	.45		.32		Temper. 600-650				
W4		.16	.60	.40	.70	.40		Air harden 920	30	53	20	5
		.21	.70	.45	.90	.45		Temper. 640-680				
WA4		.20	.40	.30	1.20		.45	Air harden 1,000	32	52	20	5
		.28	.70	.50	1.50		.55	Temper. 670				
W4V		.20	max.	max.	1.00	.20	.20	Air harden 920	30	52	20	5
		.28	.70	.40	1.40	.25	.30	Temper. 670				
W6S		.15	.50	.85	.80	1.00	.50	Water harden 1,100	50	65	16	8
		.20	.60	.95	1.00	1.20	.60	Temper. 650-680	60	75	8	4
W6SA		.15	.40	.80	1.00	.30	.50	Water harden 1,100	45	60	16	12
		.20	.50	.90	1.10	.35						
W8	0.40	.20	16.00	1.00	11.00	1.00	.50	Oil water harden				
								1,100	38	70	40	15
	.50Ti	.25	17.00	1.10	12.00	1.10	.60	Stress relief 400				
	.25	.15	17.50	.80	9.00		.40	Oil or water				
								harden 1,150	32	65	30	12
	.35	.20	19.00	1.10	10.00		.50	Stress relief 400				

TABLE D. – Unalloyed special steel castings

Mark	C	Mn	Si	P	S	Heat treatment, °C.	Mechanical properties: Yield, 0.2 percent	Mechanical properties: Max. strength	Mechanical properties: Elong. (L=5D)	Impact, mkg/cm² DVM	VGB
M15	0.14	0.40	0.30	max.	max.	Anneal 920	18	38	25	(8)	
Stg38/D81	.19	.60	.50	0.05	0.05	Temper. 650					
M19	.20	.45	.30	max.	max.	Anneal 920	25	45	22	4	6
Stg45/D81u.	.28	.65	.50	0.05	0.05	Temper. 650					
M23	.30	.45	.30	max.	max.	Anneal 920	25	52	18		(5)
Stg52/D81	.38	.70	.90	0.05	0.05	Temper. 650					
H60	.40	.50	.30	max.	max.	Harden 860	(36)	60	(15)	(15)	8
Stg60/D81	.50	.75	.50	0.05	0.05	Temper. 570					
N50	.50	.60	.30	max.	max.	Harden 860	45	70	10		
	.60	.80	.50	0.035	0.030	Temper. 570					
A115	.12	.50	max.	max.	max.	Anneal 920	18	38	25		
	.17	.60	0.03	0.035	0.030						
		(With addition of Al)									

Manganese-alloyed special steel castings

Mark	C	Mn	Si	P	S	Heat treatment, °C.	Mechanical properties: Yield, 0.2 percent	Mechanical properties: Max. strength	Mechanical properties: Elong. (L=5D)	Impact, mkg/cm² DVM	VGB
M30	0.20	0.90	0.30			Anneal 900	27	50	20	4	5
Mn Stg50/D82	.28	1.20	.60			Temper. 650					
M35	.32	1.20	.30	max.	max.	Anneal 920	45	65-75	18		6
	.40	1.50	.50	0.035	0.030	Oil harden 870					
						Temper. 570					
M45	.40	1.40	max.	max.	max.	Anneal 920	50	75-85	15		
	.48	1.60	0.40	0.035	0.030	Oil harden 860					
						Temper. 560					
MnH	1.10	11.00	max.	max.	max.	Heat slowly to 1,000	45	75-85	30-40		
						Quench in water					

TABLE E

	Analysis, percent							
	C	Mn	Si	Cr	Mo	V	Ni	Heat treatment, °F.1/
MV25	0.18	0.90	0.20	-	-	max.	-	N 1832-2012; WQ 1688; T 1256
	.25	1.20	.50			0.10		
CMV16	.14	1.20	max.	2.40	0.45	.20	-	N 1832; OQ 1688; T 1256
	.19	1.40	0.45	2.60	.45	.25		
CV16	.14	1.20	max.	2.40	-	.10	-	N 1832; OQ 1688; T 1256
	.19	1.40	0.45	2.60		.20		
P1	.28	.60	.35	3.20	.40	.10	-	N 1742; OQ 1616; T 932
	.33	.70	.40	3.40	.50			
P2	.32	.60	.20	2.00	.20	max.	-	N 1742; OQ 1616; T 1238
	.42	.90	.50	2.60	.30	0.15		
P3	.32	.60	.20	2.00	-	max.	0.70	N 1742; OQ 1616; T 1238
	.42	.90	.50	2.60		0.15	1.20	
P4	.32	.60	.20	2.00	-	-	-	N 1742; OQ 1616; T 1208
	.42	.90	.50	2.60				
T	.20	.30	.50	14.00	-	-	-	N 1922; T 1256
	.30	.50	.80	15.00				
MSK	.25	.80	.50	-	-	-	-	N 1742; WQ 1580; T 1076-1178
	.30	1.00	.70					
M19	.20	.45	.30	-	-	-	-	N 1688; T 1202
	.28	.65	.50					
M23	.30	.45	.30	-	-	-	-	N 1688; T 1202
	.38	.70	.50					
H60	.40	.50	.30	-	-	-	-	N 1616; T 1058
	.50	.75	.50					

Mark	Tensile psi	Yield psi	Elong. percent l=5d	R.A., per-cent	Impact, ft.-lb.	
MV25	78,000	57,000	15	50	-	Navy steel castings.
CMV16	88,500	64,000	20	65	-	Submarine armor.
CV16	88,500	64,000	15	65	-	Do.
P1	156,500	135,000	7	-	14	Army armor.
	178,000					
P2	114,000	2/75	10	-	60	Army armor, sections over 3 inches.
	135,000					
P3	107,000	100,000	10	-	60	Army armor.
	128,000					
P4	107,000	100,000	10	-	60	Do.
	128,000					
T	92,500	57,000	12	-	-	Navy centrifugal pump torpedos.
	107,000					
MSK	107,000	71,000	12	-	45	Track shoes armored carriages.
	128,000					
M19	64,000	36,000	22	-	40	Submarine castings.
M23	74,000	36,000	18	-	38	Engine, steam conduits.
M60	85,500	51,500	15	-	60	Tank track shoes.

1/ N = normalizing temperature; WQ = water-quenching temperature; OQ = oil-quenching temperature; T = tempering temperature.

2/ Percent.

TABLE F

Mark	Analysis, percent						Heat treatment, °F.
	C	Mn	Si	Cr	Mo	V	
W68	0.15	0.50	0.85	0.80	1.00	0.50	N 1688; O or W quenched; T 1256
	.20	.60	.95	1.00	1.20	.60	
W6HE	.10	.30	1.20	1.50	-	.23	N 1688; OQ; T 1256
	.16	.50	1.60	1.80		.35	

Mark	Yield psi	Tensile psi	Elong., percent L=5d	R.A., percent	Impact, ft.-lb.	Use
W68	71,000	92,000	16	-	58	Heat-resistant castings.
W6HE	42,500	78,000	18	-	29	Hydraulic castings.
		92,000				

TABLE G

Mark	Analysis, percent							Heat treatment, °F.
	C	Mn	Si	Cr	Mo	V	Ti	
W8	0.20	16.00	1.00	11.00	1.00	0.50	0.40	N 1922; OQ or WQ; T 752
	.25	17.00	1.10	12.00	1.10	.60	.50	
WA8	.15	17.50	.80	9.00	-	.40	.25	N 2070; OQ or WQ; T 752
	.20	19.00	1.10	10.00		.50	.35	

Mark	Yield psi	Tensile psi	Elong., percent L=5d	R.A., percent	Impact, ft.-lb.	Use
W8	54,000	100,000	40	-	108	Jet carrier steel castings for V-2 bombs.
WA8	46,000	92,000	30	-	87	

TABLE H

Mark	Analysis, percent					Heat treatment, °F.
	C	Mn	Si	P	S	
M 15	0.14 .19	0.40 .60	0.30 .50	0.050 max.	0.050 max.	N 1688; T 1200.
M 19	.20 .28	.45 .65	.30 .50	0.050 max.	0.050 max.	N 1688; T 1200.
M 23	.30 .38	.45 .70	.30 .50	0.050 max.	0.050 max.	N 1688; T 1200.
H 60	.40 .50	.50 .75	.30 .50	0.050 max.	0.050 max.	N 1616; WQ; T 1058.
Al 15	.12 .17 (with aluminum addition)	.50 .60	.30 max.	0.035 max.	0.030 max.	Anneal 1688.

Mark	Yield psi	Tensile psi	Elong., percent L=5d	Impact, ft.-lb.	Use
M 15	26,000	54,000	25	50	Cast steels used in the construction of boiler equipment. The specifications are set up by Association of Boiler manufacturers and German Society for Testing Materials.
M 19	36,000	64,000	22	36	
M 23	36,000	74,000	18	36	
H 60	51,000	85,000	15	58	
Al 15	26,000	54,000	25	-	

Mark	Analysis, percent					Heat treatment, °F.
	C	Mn	Si	Cr	V	
CV42	0.40 .48	1.00 1.30	0.50 max.	1.80 2.00	0.15 .25	N 1832-2012; OQ.
CV30	.25 .35	.50 .80	0.20 .50	1.20 1.50	.15 max.	N 1832-2012; OQ.

Mark	Yield psi	Tensile psi	Elong., percent L=5d	Impact, ft.-lb.	Use
CV42	-	128,000 156,000	-	-	Cast steel for drop forge blocks.
CV30	75 percent	114,000 135,000	10	36	

TABLE I

Mark	Analysis, percent							Heat treatment, °F.
	C	Mn	Si	Cr	Mo	V	Ti	
PL1	1.30 1.60	0.35 .85	0.80 1.10	0.35 .55	-	-	-	N 1652; T 1400.
PMS	.40 .50	1.20 1.50	.80 1.10	-	-	-	-	N or OQ.
PCV	.28 .35	.80 1.00	.30 .50	1.00 1.20	- -	0.08 .15	-	N; OQ or WQ.
PCMV	.35 .40	.90 1.00	.30 .40	1.10 1.30	0.20 .30	.20 .25	-	N; OQ or WQ.
PW6E	.37 .45	.60 .85	.30 .30	1.30 1.50	.60 .70	.25 .35	-	N; OQ.
IK1	max. 0.10	.50 .70	.30 .50	-	-	-	0.50 .60	A 1688-1742
IK3	max. 0.15	3.80 4.00	.25 .40	-	-	-	-	A 1580-1652

Mark	Tensile strength, psi	Uses
PL1	113,700-135,000	Steel castings for stamping and punching machinery.
PMS	113,000-128,000 N; 128,000-164,000 OQ	
PCV	113,000-128,000	
PCMV	128,000-142,000	Experimental cast steel for aluminum rolling equipment.
PW6E	185,000-199,000	
IK1	No properties given	Steel suitable for INKROM method; that is, enrichment of casting surfaces with chromium.
IK3	do.	

TABLE J

Mark	Analysis, percent						Heat treatment, °F.
	C	Mn	Si	P	S	Cr	
C53	0.50	1.00	0.40	-	-	0.90	A 1616.
	.55	1.20	.45	-	-	1.00	
S50	.45	.60	1.30	max.	max.	-	N 1742; or OQ; T 932-1112.
	.50	.70	1.50	0.035	0.030	-	
MS30	.30	1.00	1.00	max.	max.	-	N 1742; N 1616; T 1200.
	.35	1.20	1.20	0.035	0.025	-	
MS45	.40	1.20	.80	max.	max.	-	N 1688; N 1580; T 1042.
	.50	1.50	1.10	0.040	0.040		
MnH	1.10	11.00	max.	max.	max.	0.50	WQ 1832.
	1.30	12.00	0.50	0.080	0.040	.70	

Mark	Tensile psi	Yield psi	Elong., percent L=5d	R.A., percent	Uses
C53	114,000	92,000	10	30	Wear-resistant steels for grinders, track shoes, pulleys, etc.
	128,000				
S50	85,000	51,000	15	-	
	106,000				
MS30	106,000	71,000	8	-	
	128,000				
MS45	85,000	57,000	15	-	
	100,000				
MnH	106,000	64,000	30	-	Austenitic manganese steel for wear resistance.
	121,000		40		

TABLE K

Mark	Analysis, percent C	Mn	Si	Cr	Heat treatment, °F.
T 3	0.20 .30	0.30 .50	0.50 .80	14.00 15.00	N 1922, 1/2 hr.; T 1256, T_2 932.
T 3h	.40 .45	.50 .60	.50 appr.	13.50 13.50	N 1832, 1/2 hr.; T_1 932; T_2 1256.
T 4	.25 .35	.30 .50	0.50 .80	16.50 17.50	N 1922, 1/2 hr.; T 1256
TA 8	.50 .70	.30 .50	2.30 2.80	12.50 13.50	N 1922; T 1256-1292
T 9	.20 .25	.50 .60	.90 1.00	19.00 20.00	N 2012; T 1256-1292.

Mark	Yield psi	Tensile psi	Elong., percent L=5d	Uses
T 3	T_1 57,000 T_2 107,000	100,000 135,000	12 3	Corrosion, salt-water, and partly acid-resisting steels for pumps, pipe fittings, etc.
T 3h	T_1 100,000 T_2 64,000	135,000 106,000	3 10	Do.
T 4	64,000	100,000	9	Do.
TA 8	57,000	100,000	10	Heat-resisting castings for furnaces and steam-engines.
T 9	64,000	106,000	8	Do.

TABLE L

Mark	Analysis, percent					Heat treatment, °F.
	C	Mn	Si	Cr	Ni	
TN1	0.15 .25	0.50 .80	0.50 .80	22.00 25.00	6.00 7.00	N 2012
TN2	.10 .20	.30 .50	1.00 2.00	17.50 18.50	8.00 9.00	N 2022
T1	.50 .70	.30 .50	1.80 2.30	27.00 29.00	-	A 1662
T2	1.10 1.30	.30 .50	.90 1.20	27.00 29.00	-	A 1562
T3	1.10 1.30	.30 .50	.80 1.20	27.00 29.00	1.60 2.00	A 1562
G8	2.60 2.80	.50	.90 1.00	7.50 8.50	-	N 1580
G1A	1.60 1.80	.50	.50	17.00 18.00	-	N 2012; T 750

Mark	Tensile psi	Yield psi	Elong., percent L=5d	Uses
TN1	78,000	43,000	25	Corrosion-resistant pump parts; valves
TN2	82,000	28,000	40	on which welding is required.
T1	92,000	71,000	8	Furnace grates; annealing boxes.
T2	No properties required			Pump parts.
T3	do.			Do.
G8	Only Brinell 650			Oil-well drilling bits.
G1A	85,000	71,000	7	Corrosion- and wear-resistant steel for agitator blades and pump parts for the chemical industry.

TABLE M

Mark	Analysis, percent						Heat treatment, °F.
	C	Mn	Si	Cr	Mo	V	
WALC	0.20 .27	0.80 1.00	0.30 .50	0.80 1.00	-	0.08 .15	N 1832; T 1238
WALS	.20 .28	.90 1.20	.30 .60	-	-	.25 .35	N 1688; T 1238
WA2S	.20 .28	.50 .80	.30 .50	.90 1.20	-	.22 .28	N 1832; T 1238
WA4	.20 .28	.40 .70	.30 .50	1.20 1.50	-	.45 .55	N 1832; T 1238
W3M	.18 .23	.60 .70	.40 .45	-	0.27 .32	-	N 1688; T 1112-1202
W4	.16 .21	.50 .70	.40 .45	.70 .90	.40 .45	-	N 1688; T 1184-1256

Mark	Yield psi	Tensile psi	Elong., percent L=5d	Impact, ft.-lb.	Uses
WA1C	40,000	71,000	20	36	Heat-resistant steel for steam chests, steam pipes, fittings, and steam turbines for Navy.
WA1S	43,000	74,000	20	36	
WA2S	46,000	78,000	20	36	
WA4	46,000	74,000	20	36	Do.
W3M	36,000	64,000	22	43	Do.
W4	43,000	75,000	20	36	Do.

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APPENDIX 3. - BERYLLIUM IN STEEL CASTINGS, RUHRSTAHL ANNENER

The purpose of the investigation was to study the effect of low beryllium additions upon the strength and ductility of cast steel. The maximum beryllium content was fixed ~~at 0.60 percent, as higher~~ percentages were known to embrittle steel.

Metal was melted in a 50-pound, high-frequency, induction furnace, and beryllium was added as ferro-beryllium shortly before tapping the heat. A heat was also made in a 2-ton electric-arc furnace. In this case the ferro-beryllium was put in a can and was then placed under the stream during tapping of the heat. Even with this precaution, a loss of 50 percent beryllium was unavoidable.

The steel was used for pouring aircraft castings averaging 200 pounds pouring weight each. After proper heat treatment, the castings were sectioned, and these sections were machined to test bar size and pulled.

Test results

Heat	Analysis			
	C	Mn	Si	Be
1	0.23	0.51	0.26	-
2	.28	.47	.31	0.03
3	.27	.59	.28	.07
4	.27	.71	.30	.14
5	.24	.74	.71	.38
6	.26	.73	.38	.61
7	.28	1.09	.60	.31
8	.22	1.10	.38	.13

Heat	Tensile strength psi	Yield psi	Elong., percent L=5d	Red. of area, percent	Impact, ft.-lb./cm
1	94,000	62,000	22.0	64.0	82.3
2	111,000	93,874	16.0	61.6	93.2
3	128,000	113,787	13.4	48.0	73.0
4	142,000	122,321	14.0	48.0	59.3
5	155,000	136,500	14.0	41.5	36.8
6	207,662	186,327	11.0	19.0	12.3
7	172,000	156,457	10.4	23.0	32.5
8	227,000	206,239	6.5	34.5	36.2

Heat treatment of heats 1 to 7: Heat to 1,600° F., quench in water, draw at 850° F., air-cool.

Heat treatment of heat 8: Heat to 1,600° F., quench in water, draw at 350° F.

Conclusions

Test results show that steel alloyed with Be in percentages of 0.07 to 0.30 has similar properties as Cr, Ni, Mo, and V steels. A superior steel, however, was not developed, and the high cost of beryllium together with the difficulty of obtaining it were factors that militated against the using the steel in production.

APPENDIX 4. - EFFECT OF VARIOUS HEAT TREATMENTS UPON CAST ARMOR STEEL, RUHRSTAHL ANNENER GUSSTAHLWERKE

An investigation was made to study the effect of various heat treatments upon a section of cast armor steel. Studies were made of the tensile properties at 20° C. (68° F.) and notched bar impact properties at 20° C. and -60° C. (-76° F.). Twelve test blocks 150 by 250 by 80 mm (approximately 6 by 10 by 3.2 inches) were cast from the following steel:

	Percent
C	0.35
Mn	.70
Si	.44
P	.039
S	.006
Cr	2.33
Ni	.19
Mo	.03

Nickel and molybdenum are present as residuals, and the phosphorus is on the high side but within specification limits.

The risers were removed from the castings, and the castings were heat-treated to the following schedule:

1. Blocks 1 and 2: Normalize at 1,742° F. for 2 hours; oil quench at 1,616° F. for 2 hours; temper at 1,238° F. for 6 hours; cool in water.

2. Blocks 3 and 4: Normalize at 1,742° F. for 2 hours; oil quench at 1,616° F. for 2 hours; temper at 1,202° F. for 6 hours; cool in water.

3. Blocks 5 and 6: Normalize at 1,742° F. for 2 hours; oil quench at 1,616° F. for 4 hours; temper at 1,238° F. for 6 hours; cool in water.

4. Blocks 7 and 8: Normalize at 1,742° F. for 2 hours; oil quench at 1,616° F. for 4 hours; temper at 1,202° F. for 6 hours; cool in water.

5. Blocks 9 and 10: Normalize at 1,742° F. for 2 hours; water quench at 1,616° F. for 2 hours; temper at 1,238° F. for 6 hours; cool in water.

6. Blocks 11 and 12: Normalize at 1,742° F. for 2 hours; water quench at 1,616° F. for 2 hours; temper at 1,202° F. for 2 hours; cool in water.

The blocks were then cut so that tensile and impact specimens were obtained from the center of the block and from the outside edge of the block. Tests were made and tabulated, as shown in table A.

A comparison of tests 1 and 2 indicated that the impact strengths were considerably reduced at the lower tempering temperature and in most instances failed to meet the minimum requirements of 8 m Kg/cm². Also, at low temperatures the impact values for specimens tempered at 1,202° F. were only about

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two-thirds of those tempered at 1,238° F. The double oil quench of test 3 did not improve the properties materially over those of the single oil quench at test 1. Also, there was little difference between the properties at the lower draw temperature when single and double oil quenching was used as proscribed in tests 2 and 4. If tests 1 and 5 and tests 2 and 6 are compared, it will be noticed that water quenching was responsible for a small increase in tensile and yield strengths.

It was found that all test bars taken from the edge of the block were higher in tensile and yield strengths than those taken from the center of the block. No outstanding differences were observed between edge and center values for elongation and reduction of area values. The impact-strength values from the center sections were always lower. It was also observed that test bars cut from areas farthest away from the riser gave the higher values for all properties.

Conclusions

Test results indicated that double oil quenching rather than single oil quenching had no practical effect upon the impact strength of test specimens irrespective of whether they were cut from the center or the edge of the block (3.2-inch section). The tempering temperature had a marked effect upon the properties.

TABLE A. - Mechanical property values of block sections, Ruhrstahl A. G., Annener Gusstahlwerk

	Tensile strength p.s.i.	Yield strength p.s.i.	Elong. L=5 dia., percent	Red. of area, percent	Impact at mkg/sq.cm., 20°C.			Impact at mkg/sq.cm., -60°C.		
					Av.	Low	High	Av.	Low	High
Edge	108,500	85,300	16.4	50	11.47	7.0	16.3	2.7	1.0	5.4
Blocks 1 and 2, center edge	105,900	82,000	15.3	40.5	9.75	5.3	13.2	2.2	1.0	5.0
Blocks 3 and 4	115,800	95,500	15.0	53.2	8.0	4.0	11.1	1.7	.8	3.4
center edge	113,900	91,000	13.4	50.5	6.4	3.1	10.7	1.3	.7	3.0
Blocks 5 and 6	104,000	81,700	18.1	54.9	12.1	7.6	15.0	2.3	.6	5.8
center edge	102,400	79,800	18.2	52.1	11.2	7.0	15.0	2.0	.9	5.3
Blocks 7 and 8	113,800	88,900	16.1	48.9	8.5	2.6	13.4	1.6	.7	4.3
center edge	110,100	85,800	14.4	40.1	7.0	4.3	13.0	1.4	.7	4.0
Blocks 9 and 10	111,300	89,600	15.9	46.1	11.3	7.3	16.0	1.7	.6	4.3
center edge	108,500	86,700	14.2	40.0	9.2	5.4	14.5	1.7	1.0	3.0
Blocks 11 and 12	120,100	99,600	14.0	47.6	7.8	2.5	15.0	1.6	.9	3.0
center	117,500	96,700	14.4	39.3	4.7	2.6	8.9	1.5	.9	3.4

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APPENDIX 5. - SPECIFICATIONS FOR HEAT-RESISTANT STEEL CASTINGS, BOCHUMER VEREIN

Specifications for heat-resistant turbine castings, as required by the S. S. W. Co., Mülheim, are as follows: Physical properties at 20° C. or 66° F., to be:

Tensile strength, lb./sq. in. min.	45,000
Yield, lb./sq. in. min.	18,000
Elongation (G. L. = 5 dia.), percent	20
Impact strength, Charpy keyhole notch, ft.-lb./sq. cm. min.	29
Creep rate at 500° C. (932° F.), lb./sq. in.	17,000

The creep rate must not exceed 0.004 percent per hour of the original gage length between the 25th and 35th hour in a short-time test of 45 hours' duration. The total amount of creep at the 45th hour shall not exceed 0.2 percent of the gage length.

The following additional requirements were specified by the customer: Castings must have a smooth finish, free from blow holes, cracks, sponginess, and slag. Welding and plugging are not permitted unless of defective areas are examined and approved for welding by customer. Surfaces to be machined must have, besides the normal finish allowed, an additional finish of 3 to 5 mm. The latter must be removed by the foundry machine shop. The castings are annealed after they are chipped and ground and again after rough machining. The second annealing eliminated any possible stresses remaining or created by the rough machining. A heat diagram of the second anneal must be furnished in duplicate, besides the chemicals and physicals.

The housing is to be tested under hydrostatic pressures specified on the drawing.

Test bars are to be an integral part of the castings and must be attached on sections outlined on the drawings. Tests must be made by Bochumer Verein, and copies of the test reports must be furnished in duplicate. The fractured bars are to be kept by Bochumer Verein at the disposal of the customer. Test bars can be scrapped only by written permission of the customer. Test bars are to be removed after the first annealing, except one, which must remain attached to the casting for re-checking by customer if he sees fit to do so.

Up to the beginning of the war, Bochumer Verein furnished heat-resistant steel for steam turbines of the following analysis:

	Percent
C	0.15-0.20
Si	.30- .50
Mn	.50- .80
Cr	.90-1.10
Mo	.25- .30

During the war, scarcity of Mo made the following analysis mandatory:

	Percent
C	0.18-0.26
Si	.30- .50
Mn	.70- .90
Cr	.90-1.10
V	.20- .25

In cases where a hot strength of 21,000 lb./sq. in. at 500° C. (932° F.) was specified, Mo steel had to be used and the Mo content raised to 0.35 to 0.45 percent.